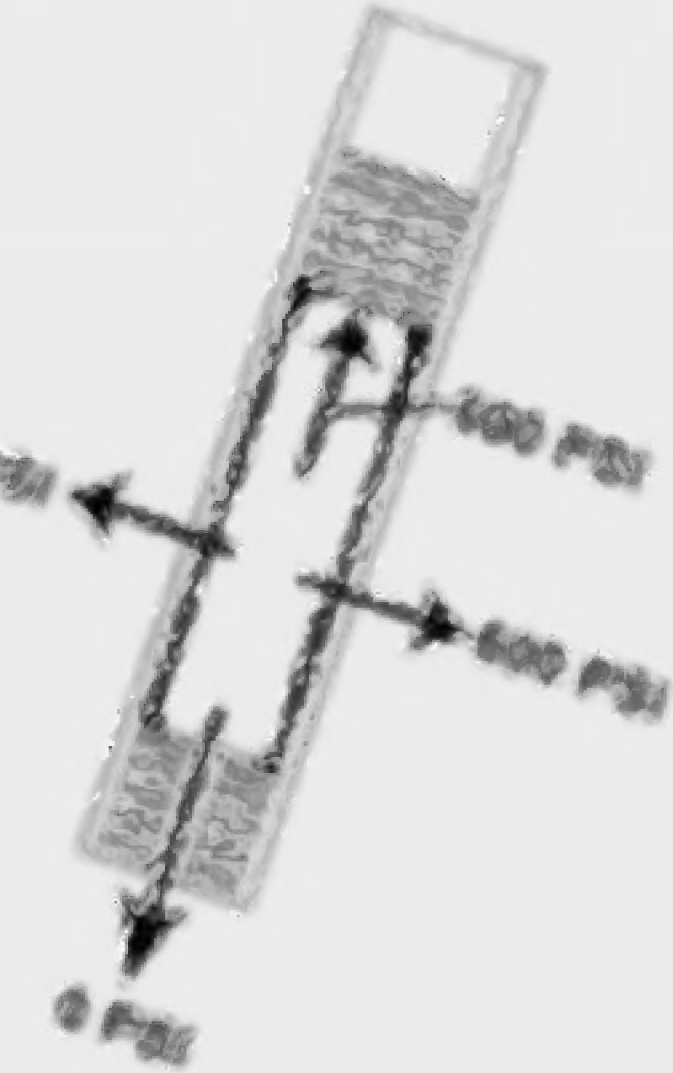
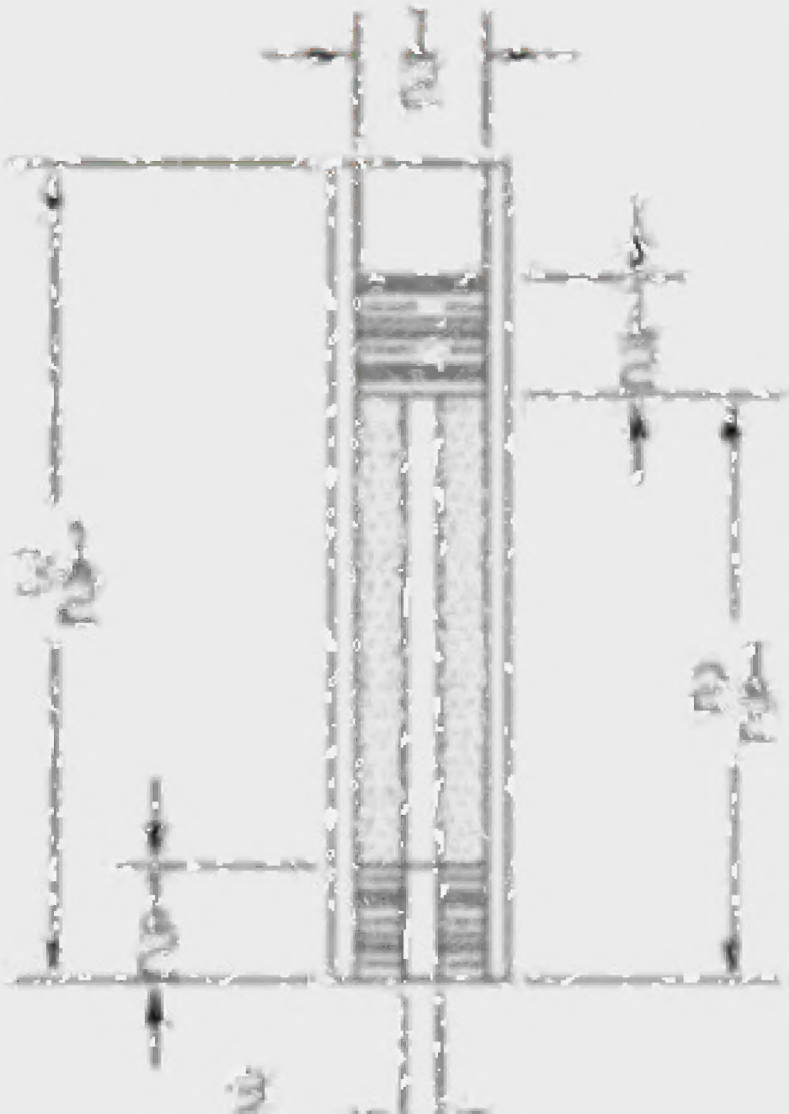
EASY PVC ROCKETS

JASON SMILEY





EASY PVC ROCKETS

by

JASON SMILEY

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SAFETY

Obviously when you are dealing with rockets and propellant you must be cautious and safe. There are a few safety rules that you should set for yourself to follow so your rocketry experience can be a fun one and not harm yourself or others or damage any property.

First of all do not smoke while making rocket engines. If you are a smoker you better just give it up or find another hobby. Keep all sources of heat sparks or open flame away from the propellant and completed rocketed engines. This includes things such as hot lamps or lights. The propellant presented in this book actually has a very high ignition point which makes it safer than others but please don't be careless or overly comfortable when working with it because accidents can happen.

Also wear goggles or better yet a face shield when ramming or drilling rocket engines. Avoid looking directly down onto the engine when ramming the propellant or when drilling the nozzle. Keep your face away from the engine at all times and keep your body as far away as possible to minimize any kind of damage to yourself if an accident would occur. If your are not turning the drill bit in by hand and are using a drill then make sure it is on low speed to keep friction down and to keep heat from building up. Also keep your work area and drill bits clean from debris and propellant.

Keep a supply of water near by and have an emergency plan incase a motor would happen to ignite during the building process. Construct the engines preferably in a garage or outside or somewhere there is little combustible material present.

DO NOT grind the propellant mixed (that is the fuel and oxidizer together) in a coffee grinder because the coffee grinder motor will heat up enough to ignite the propellant in the grinder. The coffee grinder is to be used for separate chemicals only where there is no chance of ignition.

Make sure your rocket engines are balanced for flight and do not fly an unbalanced rocket because some of these engines could cause serious harm or damage if they would hit you or your property. Some of the higher end engines have over 25lbs of thrust and this could cause some serious harm if it was unbalanced and flew off course.

Fly rockets in an open field away from property and stand a hundred feet or more away from them when firing. Make sure it is not dry out and there are no combustible materials near by when you launch a rocket. These rockets do get hot and if it lands in a pile of dry grass it could pose a fire hazard.

Check your local laws about model rocketry and stick rockets and do not sell your rocket engines or propellant.

Also if you are worried about the PVC pipe exploding…don't be. Because of the design the clay end caps will blow out long before the PVC pipe will break. The PVC pipe can handle pressures much greater than the clay end caps can. But be careful of flying clay because this could injure you as well. Just make sure you are always a safe distance away from your rockets when you fire them.

Although the propellant and procedures in this book are very safe you still must use common sense when building and firing rockets. Ultimately safety is left up to you and you must be able to take on the responsibility and if you cannot you have no place in making rocket engines or in model rocketry. If you are cautious and use common sense about safety rules you should have a fun and educational experience.

BASIC CONCEPTS OF ROCKETRY

There are various types of rocket motors utilizing many types of propellants and varying in complexity. The rockets presented in this book are of the simplest and use a solid fuel propellant. By solid fuel I mean that the propellant in the rocket engines is in a solid state such as a powder. The propellant is a mixture of a fuel and an oxidizer. The fuel in these rocket motors is powdered sugar or sucrose and the oxidizer is the potassium nitrate. Potassium nitrate will not burn at all on its own unless it is presented with a fuel source and sugar burns mildly because it does have an oxygen source that it needs to burn mildly and that is the oxygen in the air. The potassium nitrate can't burn because there is no fuel source in the air for it to provide its oxygen's to. But when these two components are mix together they will burn violently and very rapidly. This is because the potassium nitrate is providing its oxygen's to the fuel that is the sugar and this all becomes a chemical equilibrium. The closer to this equilibrium the faster the propellant will burn.

The potassium nitrate and the sucrose are in a stable state until you add an energy source to them to give them the required energy to convert over to gaseous products. The required energy breaks the molecular bonds and they recombine to form various products most of which are gases. This required energy is simply a flame or heat energy.

This is the chemical equilibrium of the potassium nitrate and sucrose:

$$C_{12}H_{22}O_{11} + 6.29\ KNO_3 \rightarrow 3.80\ CO_2 + 5.21\ CO + 7.79\ H_2O + 3.07\ H_2 + 3.14\ N_2 + 3.00\ K_2CO_3 + 0.27\ KOH$$

The compounds are symbolized as:

sucrose	solid	$C_{12}H_{22}O_{11}$
potassium nitrate	solid	KNO_3
carbon dioxide	gas	CO_2
carbon monoxide	gas	CO
steam	gas	H_2O
hydrogen	gas	H_2
nitrogen	gas	N_2
potassium carbonate	liquid	K_2CO_3
potassium hydroxide	liquid	KOH

In a rocket engine the propellant burns and produces these gases, which inside a closed space builds up pressure since there is nowhere for these rapidly expanding gases to go. The rocket engine has a hole at the bottom called a nozzle for the gasses to be released but they cannot be released fast enough without having a large pressure built up inside the rocket. As the propellant burns there is a pressure on all sides of the engine. The pressures on the sides of the tube equal each other out since there is a pressure pushing right and a pressure pushing left. It is like a tug of war game in which neither side can win since they are of equal strength. There is also a pressure pushing up toward the top of the engine and there is a pressure pushing down toward the bottom of the engine. Since there is a nozzle at the bottom of the engine the gases can escape and the pressure drops at this point near zero. But the pressure at the top has nowhere to go so it is pushing upward with full force. And in this tug of war game the pressure at the top is much stronger than the pressure at the bottom so it is going to win. With all the pressure at the top and little at the bottom the rocket streaks forward up into the sky. This is the theory on how the rocket engine works.

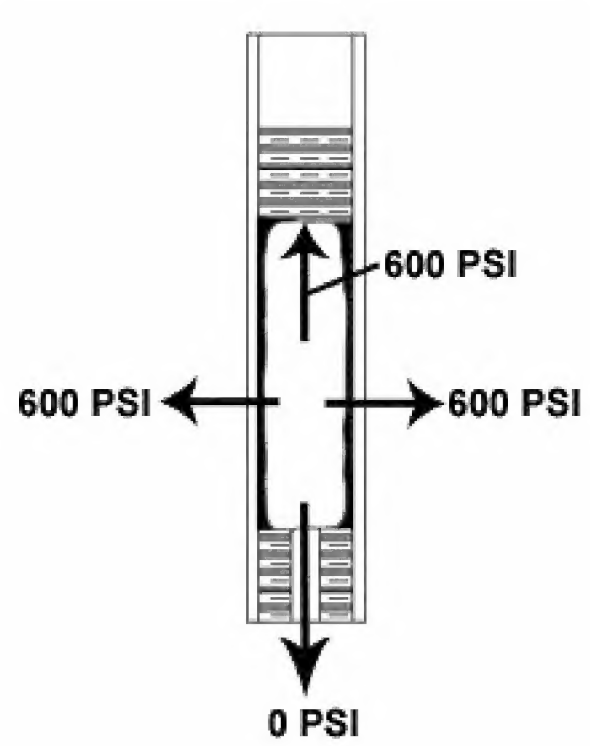


Figure 2-1: The pressure on the sides equal out but the top and bottom are not equal so the pressure at the top pushes the rocket upward.

But you cannot just simply pack this particular propellant into a tube with a nozzle and hope it will fly. This particular propellant is too slow burning for it to produce enough gas fast enough to create the kind of pressures to make the rocket capable of flying. So to make this propellant burn faster you have to increase the surface area of the burning propellant. If the propellant were just simply packed into a tube the surface of the burning would just be at the bottom and work its way up and would not be very large. To increase the surface area of the burning propellant you must core it. When I say core it I mean you have the have a hollow "core" through the propellant lengthwise. For these rockets we will just simply drill out a hollow space through the length of the propellant in the tube. This will successfully create a cavity where a much greater surface of the propellant is exposed to the flame and this will create enough pressure for the rocket to be capable of flying.

This type of rocket is called a core burner, because of its core area that is burning. See the diagram below for a cutaway view of a core burner engine.

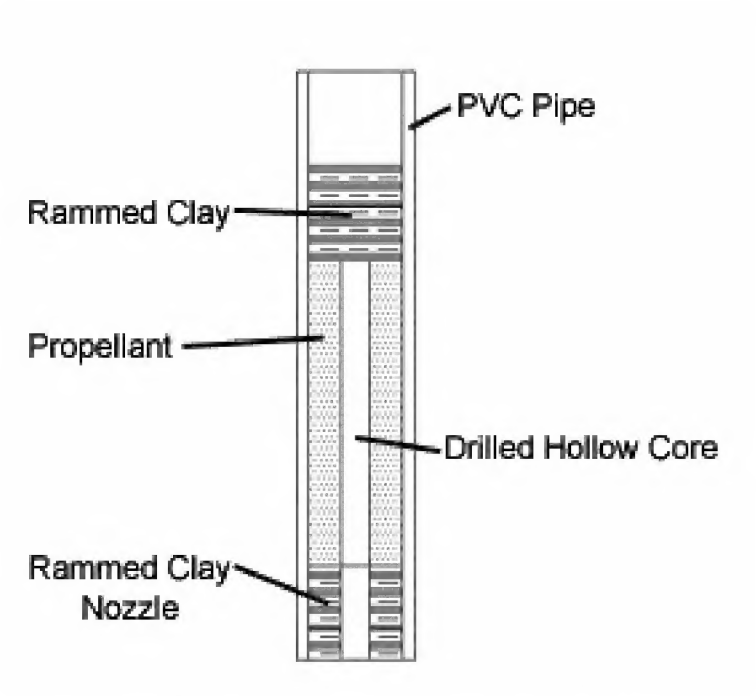


Figure 2-2: Cutaway view of a core-burning engine.

As you ignite the cored propellant in the engine it starts to all burn at once and proceeds to burn toward the case from the center. As this burning progresses the core gets wider and the surface area will constantly increase and so will the pressure in the engine and if the pressure increases the thrust of the engine will increase as well.

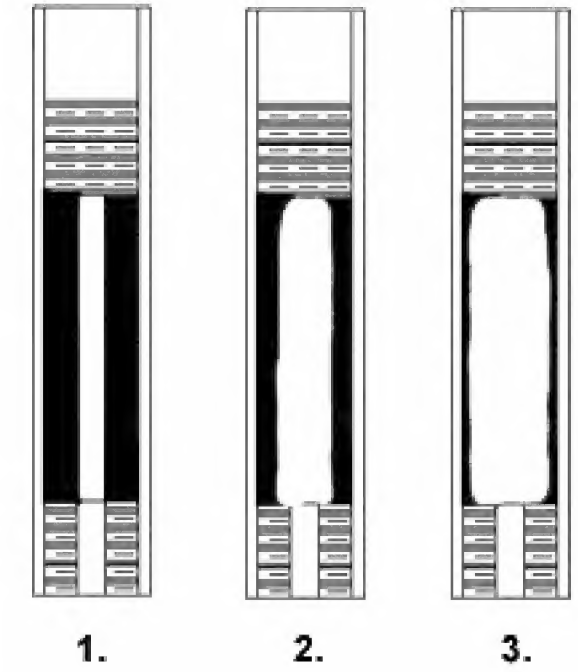


Figure 2-3: The burning propellant in the engine progresses outwards and the surface area of the burning propellant increases.

So when the engine is first fired it is at its minimal pressure and thrust and then steadily increases through its flight. The pressure graph is presented blew for this type of engine and it shows this concept.

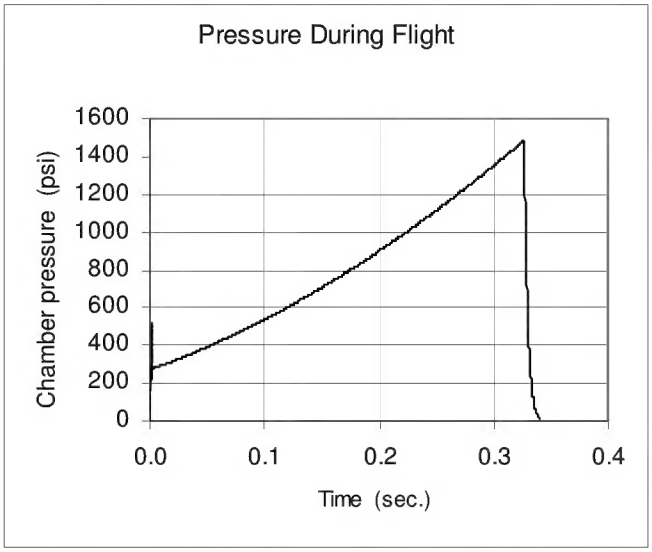


Figure 2-4: The pressure steadily increases during the burn of the rocket engine.

As you can see the pressure will keep increasing in the engine until it runs out of propellant where it will suddenly drop to zero. This also applies for thrust of the engine.

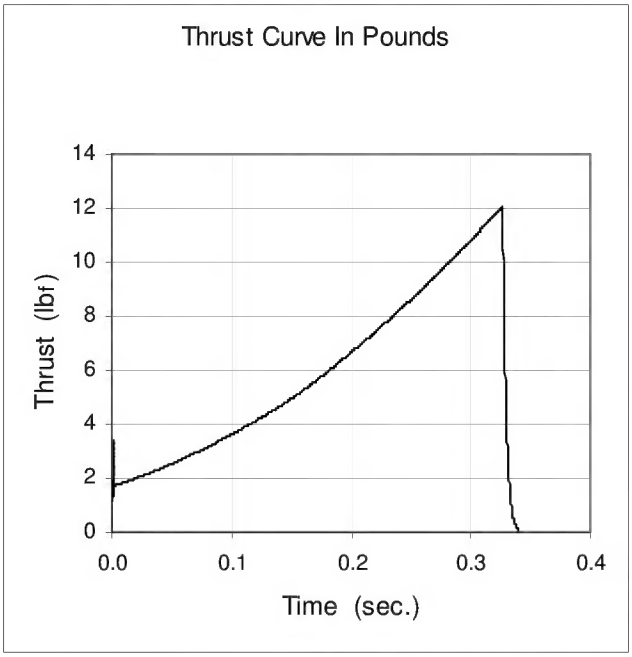


Figure 2-5: The thrust of the engine follows the same trend as the pressure since they are in direct correlation to each other.

Also keep in mind that in this engine as the pressure increases so does the burn rate of the propellant. This is why calculations for rocketry are so complicated because everything is constantly changing and you have to take in account for all of this. The area of math that is best utilized in figuring out all the equations is

called calculus but my goal of this book is to keep everything simple and easy to understand so I will not be going into this area of rocketry.

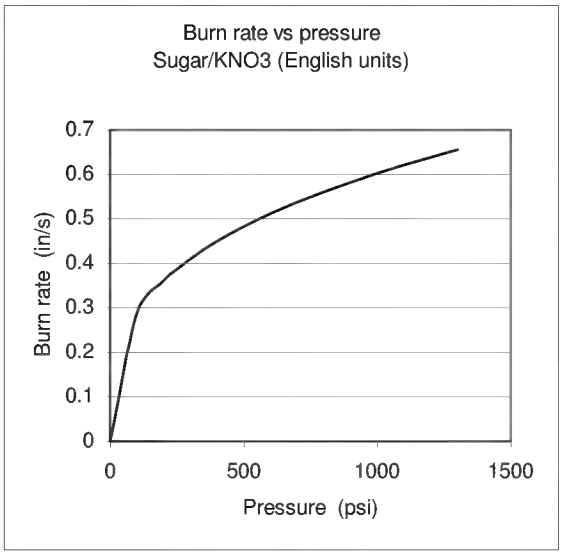


Figure 2-6: As the pressure increase so does the burn rate of the propellant.

Commercial rocket engines, such as Estes, use a code to classify their engines. The first letter in the code symbolizes an impulse range of the rocket in Newton's per second. See the table below for the list of ranges for the lettering system used in model rocketry.

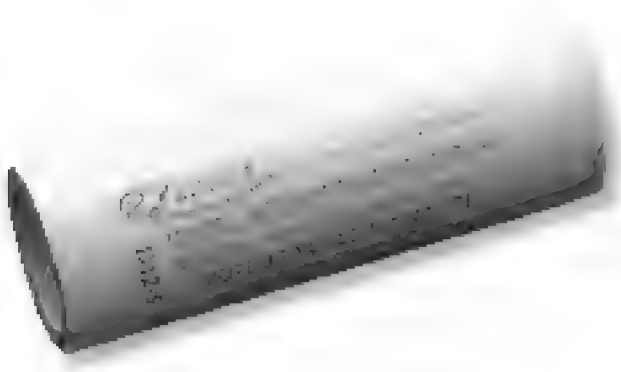


Figure 2-7: A commercial Estes rocket engine with the code "D12-5".

Rocket Motor Classification	
Class	Total Impulse (Newton-sec.)
1/4A	0 - 0.625
1/2A	0.626 - 1.25
A	1.26 - 2.5
B	2.5 - 5
C	5 - 10
D	10 - 20
E	20 - 40

F	40 - 80
G	80 - 160
H	160 - 320
I	320 - 640
J	640 - 1280
K	1280 - 2560
L	2560 - 5120
M	5120 - 10240
N	10240 - 20480
O	20480 - 40960
P	40960 - 81920
Q	81920 - 163840

The number following the letter is the average thrust in Newton's. And the number after the dash is the delay time in seconds before the parachute ejection. So the Estes engine pictured above with a code D12-5 means it has an impulse range of 10-20 N-sec and has an average thrust of 12 Newton's and has a time delay until ejection of 5 seconds. So in general the higher the letter and the number the more powerful the rocket engine will be. I will also be using this coding system to classify the rockets in this book.

MOTOR TUBES

The cheapest and easiest and quickest tubes that are available to virtually everyone is PVC pipe. PVC pipe is found at just about every hardware store in the plumbing section. It is cheap and light weight and can contain very high pressures which makes them perfect for building rocket engines. Also using PVC pipe as the casing for these rockets makes sure that you are using a standard size and that all the rockets are uniform in build.

1/4A6 and 1/2A13 Motor Designs:

For these motors there is no PVC pipe small enough to make them with. So we are going to have to improvise. For these little mini engines I use the plastic tube from a pen. Just buy a pack of cheap pens that are 3/16-inch internal diameter (I used the cheap Papermate ones) and take the front and back ends off with your fingers or pliers and take out the ink tube inside and you should be left with a plastic tube. Just cut the tube to the size you need with scissors or a hack saw and proceed to build your rocket engine.

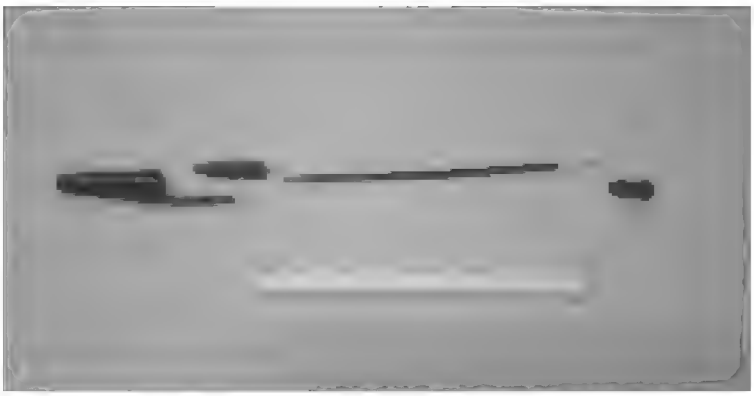


Figure 3-1: Disassemble a pen for tubes for the mini engines.

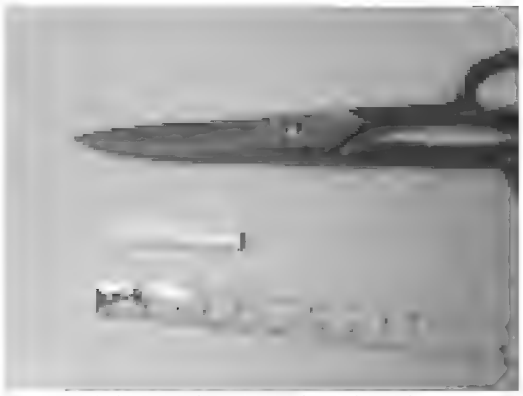


Figure 3-2: Cut the pen to length with scissors.

A7, B8, B11, C15, C19, C26, C29, and D31 Motor Designs:

For these engines you are going to need ½ inch CPVC pipe. It is **NOT** the regular ½ inch schedule 40 PVC pipe. The regular ½ inch schedule 40 PVC pipe is actually 5/8-inch internal diameter and is not useful for these designs. The CPVC is exactly ½ inch internal diameter so you must use it. The CPVC is in the same place as the PVC in the plumbing section of the hardware store. It is a yellowish/cream color normally. Just cut the pipe with a hack saw to the desired length for use.

Figure 3-3: ½ inch CPVC pipe.

C11, D18, D22, D26, D34, and E45 Motor Designs:
For these motors you will need the ¾ inch schedule 40 PVC pipe. It is also in the plumbing section of the hardware store. Just cut the PVC pipe to length using a hacksaw.

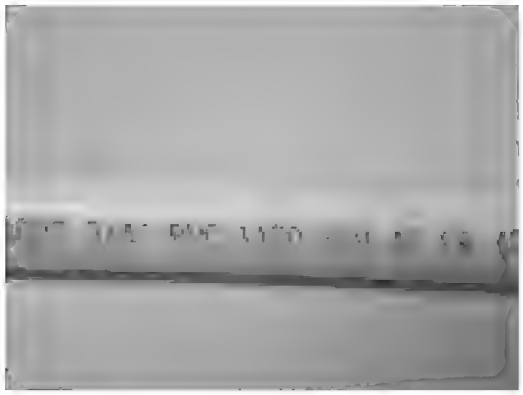


Figure 3-4: ¾ inch PVC pipe.

E28, E33, E39, E49, E54, F62, and F67 Motor Designs:
For these motors you will need the 1-inch schedule 40 PVC pipe. It is also in the plumbing section of the hardware store. Just cut the PVC pipe to length using a hacksaw.

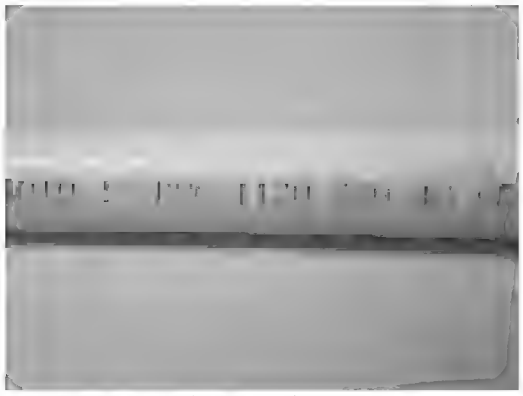


Figure 3-5: 1 inch PVC pipe.

NOZZLE CLAY

Nozzle clay is used to make the nozzles in the rocket engines you will be constructing in this book. I started out using Durham's Rock Hard Water Putty for nozzles but it required using water to mix the putty which is not good for the propellant because it is hydroscopic and will draw the moisture into it. Also it is not good for making a rocket engine quickly since it requires drying for a few days. After some time I figured I would try ramming powdered clay for a nozzle but I did not have any art supply stores available in my area to obtain this type of clay so I got the next best thing… kitty litter. Yes you heard correctly I use kitty litter or cat litter to make my nozzles for my rocket engines.

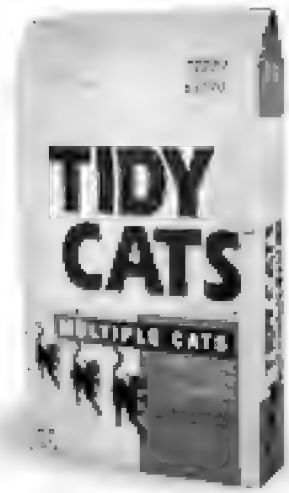


Figure 4-1: Cat litter is used for the clay in the nozzles. Get the cheap stuff.

I chose kitty litter for a couple reasons. It is cheap and easy to find and it works well if prepared properly. It also doesn't have to have time to dry so the rocket can be loaded and used right away!

Kitty litter can be purchased at just about any grocery store. Just buy the cheap stuff and I would hope you know not to buy the freshener litter that smells pretty unless you want your rockets to have a nice odor. When you open the bag it is in the form of hard rock like chunks that are too large for use as nozzle clay so it needs to be powdered. So get a small coffee grinder from the store and put a handful of the litter into it and turn it on for about 30 seconds. When you open it up the litter should now be a fine powder.

Figure 4-2: A coffee grinder is used to powder the kitty litter.

Take the fine powder and add a little water to it just enough to moisten it so it will pack better and make a harder nozzle. The amount of water to add is hard to say. You just have to eye it up. Don't dampen the clay too much though. It should appear dry but have a slight color change from the original powdered litter and

it might clump a little so stir it around with a spoon so the moisture is even in the litter. It may take some practice to get the amount correct. Once you have your damp clay it is now ready to be rammed into the tubes of your rockets.

Figure 4-3: Left – cat litter after milling with a coffee grinder. Right – course cat litter out of the bag.

RAMMING TOOLS

To be able to pack the nozzle clay and propellant into the PVC tubes of the engines you are going to need a tool to ram the mixtures in. For this purpose I just use a simple wooden dowel rod. You can buy dowel rods at any hardware store and even places like Wal-Mart sell them in the crafts section. They are basically wooden rods that are different sizes in diameter. Depending on the rocket motor you are making you will need different dowel sizes.

To make the tool you will have to be able to measure the distances inside the tube you are ramming to see how far up your nozzle or propellant is. So I like to make the dowel rod a measuring stick as well. I just put a tape measure or ruler up against the dowel and mark off inches to make it into a ruler itself. I like to mark off down to ¼ of an inch.

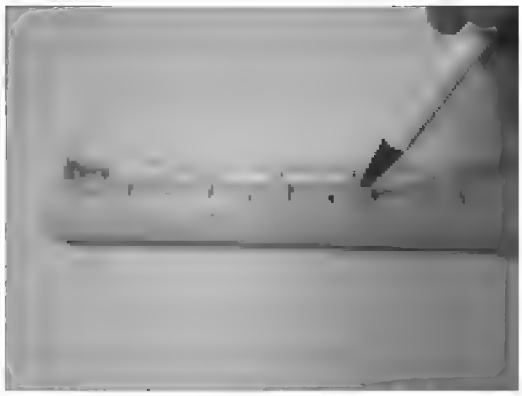


Figure 5-1: A dowel ramming tool with ¼ inches marked off.

1/4A6 and 1/2A13 Motor Designs:
For these motors you are going to need a dowel tool that is made from a 1/8-inch diameter dowel rod or a dowel that just fits inside the tube.

A7, B8, B11, C15, C19, C26, C29, and D31 Motor Designs:
These engines require a dowel rod that is 3/8 inch in diameter to fit into the ½ inch tube.

C11, D18, D22, D26, D34, and E45 Motor Designs:
These engines require a dowel rod that is 3/4 inch in diameter to fit into the tube.

E28, E33, E39, E49, E54, F62, and F67 Motor Designs:
These engines require a dowel rod that is 1 inch in diameter to fit into the tube.

CHEMICALS

SUCROSE (Also called Sugar, Powdered Sugar, and Icing Sugar)
$C_{12}H_{22}O_{11}$

Sucrose is just ordinary sugar used in cooking and it is easily found in any grocery store in the cooking isle. For rocketry it is used as the fuel in the propellant and for our propellant to be able to burn as fast as possible we need the sugar to be a very fine powder. Therefore make sure you purchase the already finely powdered "confectioner's sugar" or "powdered sugar". The good thing about using powdered sugar as a fuel for the rockets is that it packs well into tubes to form a hard mass so solvents are not necessary and this eliminates time for drying. It is also very cheap and very readily available. However on the downside this sugar makes the propellant hydroscopic, which means it will draw moisture from the air and make the propellant damp and this will drastically affect the burn rate of the propellant and the performance of the rocket so the finished propellant must be kept dry.

Figure 6-1: Powdered sugar is a fuel for rocket motors.

POTASSIUM NITRATE (Also called Salt Peter, Niter, and Nitrate of Potash)
KNO_3

Potassium nitrate is the oxidizer chemical in the rocket propellant and is a little trickier to find but usually still very common. There are a number of sources you can look for this chemical.

Stump Remover:
One source would be in stump remover. Stump remover is used to degrade stumps over time and is usually sold in hardware stores in the gardening section. It usually comes in 1lb plastic bottles and sometimes a small cardboard box. There are various brands and kinds of stump remover however and you must be sure to get the correct one. Look at the label on the container and see if it says something like "contains potassium nitrate". If it says this you have the right kind and it is normally 99% pure potassium nitrate. It should be a white crystalline powder. I personally buy the Green Light brand stump remover and it works great. Stump remover is relatively cheap as well but not as cheap as the powdered sugar. Other Brands are available but watch out because not all stump removers are potassium nitrate and other brands may not be pure potassium nitrate but if it is a white powder it is probably pure enough for use in rockets.

Figure 6-2: Green Light stump remover is pure potassium nitrate.

Figure 6-3: Other brands of stump remover that maybe pure.

If you have stump remover that is not pure potassium nitrate such as Dexol brand you could purify it through dissolving it in water and filtering because potassium nitrate is soluble in water and other things that maybe in the stump remover are not. To purify just dissolve 1lb of stump remover in 16oz (2 cups) of boiling water and stir for a few minutes to dissolve the potassium nitrate into the water. Now filter the water through a coffee filter and a funnel or a kitchen strainer so that the coffee filter filters the other solids in the stump remover out and the water is free of solids. Discard the filter and solid matter that is in it. Take the filtered water solution, which should now contain your potassium nitrate, and boil it down until there is very little water remaining and then let it evaporate off in the sun. A white powder should be remaining. The powder must be dried further by placing it on a cookie sheet in an oven set at 250 degrees Fahrenheit for about 15 minutes. Don't worry; potassium nitrate is not flammable until it is mixed with a fuel so the heat will not ignite it.

Figure 6-4: Dexol stump remover is not pure potassium nitrate but can be purified with water.

Chemical Suppliers:
There are also various chemical/pyrotechnic suppliers out there that you can order potassium nitrate from. They are usually a little more expensive but you can get the potassium nitrate through mail order. Just search the Internet for companies such as Firefox or Skylighter to name a few. Other places on the net that sell potassium nitrate are online auctions such as Ebay. The drug store may also have potassium nitrate over the counter. You have to ask for it usually because they keep it behind the counter and it is supposedly a high grade so they usually will charge a lot for it so I would use this as a last resort. Also laboratory chemical supplies will have it but will charge a lot for it as well.

Fertilizer:
Another very cheap source would be potassium nitrate fertilizer. Search garden shops for this and usually it will be in a 50lb bag or possibly in 5lb boxes. There is an NPK code on all fertilizers and the one for potassium nitrate is "13.75-0-44.50". Other manufactures may round these numbers to something like "13.5-0-45" or "13-0-44". If it has these numbers on it then it is potassium nitrate and if the numbers are different then it is not potassium nitrate. One brand name is KPower and is found in some garden shops/fertilizer stores. The potassium nitrate fertilizer is also pure and it is a white powder or white prills.

Figure 6-5: A couple brands of potassium nitrate fertilizer.

BLACK POWDER (Also called Gunpowder)
Mix of KNO_3/S/C

Black powder is used to prime smaller engines that can't fit an igniter in their core and for parachute ejection. You can purchase this from a local gun shop. I get Goex FFFF grade black powder. The more F's in the grade the smaller the grain size of the black powder and the faster it will burn. FFFF seems to work nicely. If you can't find Goex then ask for another brand of black powder or as a last resort get Pyrodex. Pyrodex is not as good as regular black powder but it will do. But **DO NOT** get smokeless powder (nitrocellulose based powders) because it requires a high pressure for it to burn fast and for our application there isn't a very high pressure and it will not burn fast enough.

Figure 6-6: Goex black powder.

Figure 6-7: Pyrodex isn't standard black powder but it may work ok in a pinch.

PROPELLANT

The propellant is the burning composition in the rocket motor that makes it fly. For an explanation of how this works read the chapter on basic concepts. There are various propellants in use today in professional and armature rocketry. The commercial Estes engines use black powder as a propellant while NASA uses a high performance mixture of ammonium perchlorate and aluminum powder along with various binders and burn rate modifiers. But the propellant we are going to use is very simplistic and probably the easiest there is. This propellant maybe simple but it is very functional and produces excellent results and you can make a high quality rocket using it.

The composition of the propellant is as follows and percentages are by weight:
Potassium nitrate (KNO_3) – 65%
Sucrose ($C_{12}H_{22}O_{11}$) – 35%

So this means if you want a 100 grams of propellant you would weigh out 65 grams of potassium nitrate and 35 grams of powdered sugar (sucrose). The same goes for any weight unit such as pounds if you prefer not to use grams.

To weigh out your chemicals you are going to need a balance or scale. I use an Ohaus triple beam balance that I purchased from Ebay. You may use other scales such as digital scales, scales used in reloading shells/bullets (powder scale), food scales, or postage scales. Look around for a scale, they can be found anywhere from office supply places to sporting goods shops. Below are some examples.

Figure 7-1: Postage scales.

Figure 7-2: Diet scale or food scale.

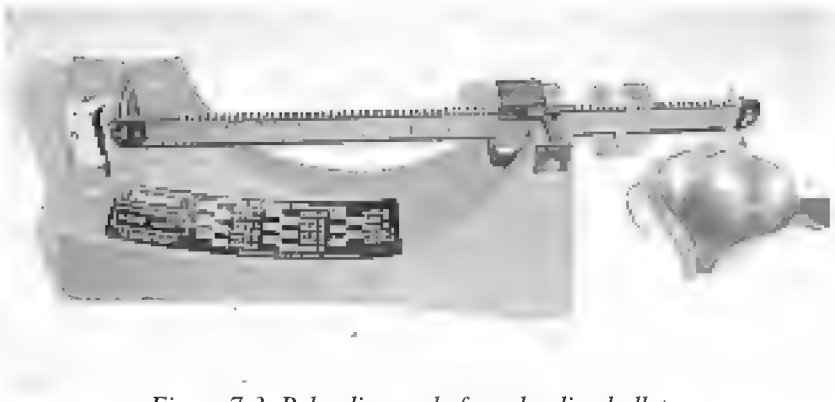


Figure 7-3: Reloading scale for reloading bullets.

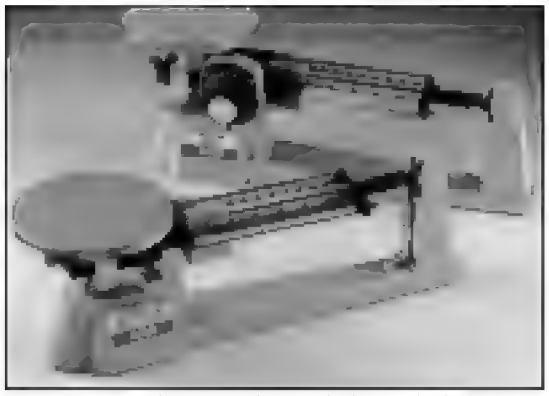


Figure 7-4: Scientific triple beam balance.

Once you weigh your chemicals place the powdered sugar into a plastic ice cream container or something similar. The powdered sugar is ready and needs no further processing. The potassium nitrate on the other hand needs to be much finer of a powder than its current state. So place the potassium nitrate into a coffee grinder and run it for about 30 seconds. A coffee grinder can be purchased from numerous stores such as Wal-Mart.

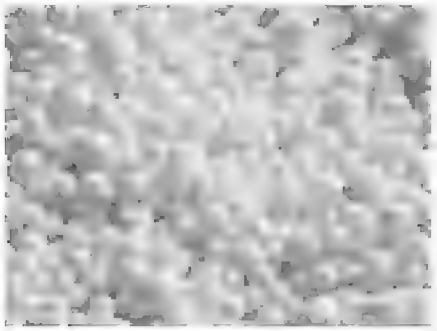


Figure 7-5: Potassium nitrate fertilizer and stump remover needs to be a much finer powder than it currently is.

Figure 7-6: A coffee grinder is used to powder the potassium nitrate.

The potassium nitrate should be a nice fine dust like powder. Dump it into the plastic container with the powdered sugar and put the lid on. Now shake the container for a few minutes to mix the propellant.

Figure 7-7: Shake the propellant in a plastic container with a lid to mix it.

After you are done shaking that is it! You now have a propellant for your rocket engines ready to be loaded.

Figure 7-8: The propellant should look like the powdered sugar and should be a fine white powder.

Do not let this propellant sit out in the open for too long because it will pick up moisture from the air and render it useless. See the section in this book on storage for information on how to store the engines and propellant.

CONSTRUCTING THE MOTORS

So now that you have all the materials and the basic concepts down about rocketry you are now ready to build your rocket engine. Make sure you read the safety chapter in this book before proceeding and that you understand the safety rules and procedures.

This chapter is to get you familiar with the construction of these engines and the procedures are the same for all the designs but with different size tubes and measurements and I hope to have you learn how to read the diagrams to be able to make the other rocket designs in this book from using the basic concepts of construction presented in this chapter. The construction techniques are the same for all the motor designs.

Lets start out small so you can get the hang of things and then work up to bigger engines. We are going to construct an A7 engine. So we are going start out by looking at the diagram design of the A7 motor from the "MOTOR DESIGNS AND DATA" chapter.

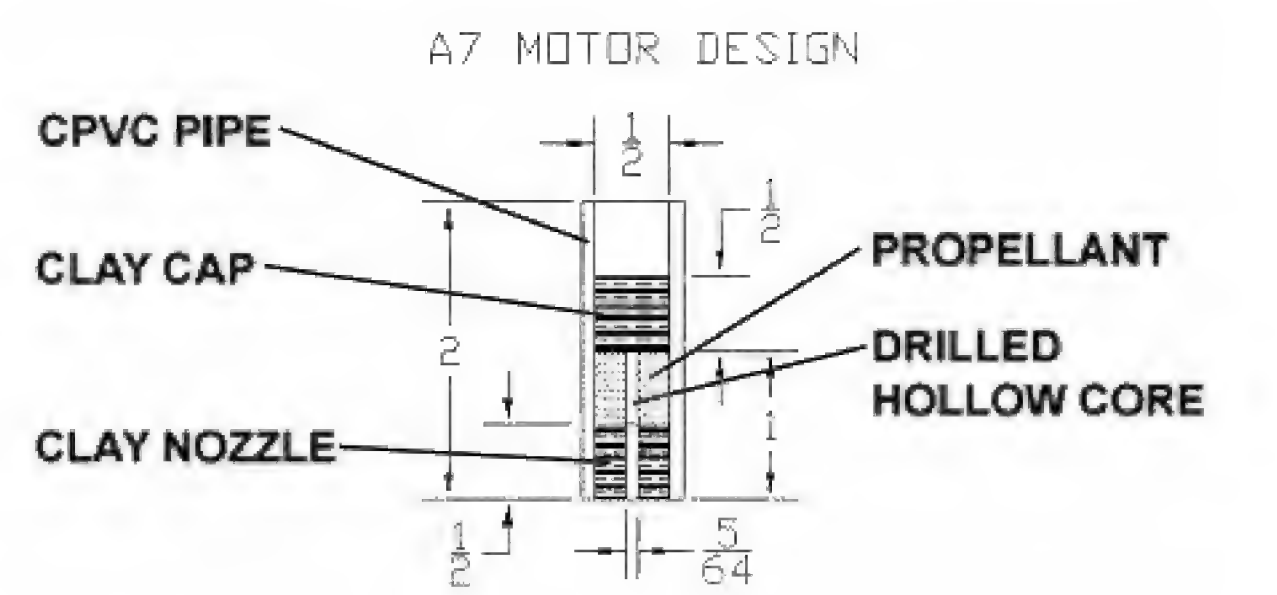


Figure 8-1: diagram of an A7 motor design.

The diagram is a cut away view of the rocket engine and the textured spots on the picture signify the same parts for all the engines that I labeled in this diagram. All units of measure on the diagrams are in inches.

The motor calls for a ½ inch internal diameter pipe so we go to the chapter on "MOTOR TUBES" to make sure of what kind of pipe we need exactly. After reading the section in this chapter I find out that I require ½ inch CPVC pipe. I get my ½ inch CPVC pipe and I cut it to the length of 2 inches (that I measured and marked with a pencil) with a hacksaw since that is that the diagram says is the total length of the motor.

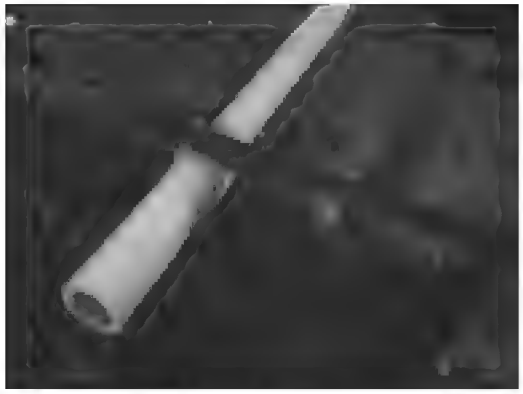


Figure 8-2: Cutting the CPVC pipe with a hack saw to the desired length.

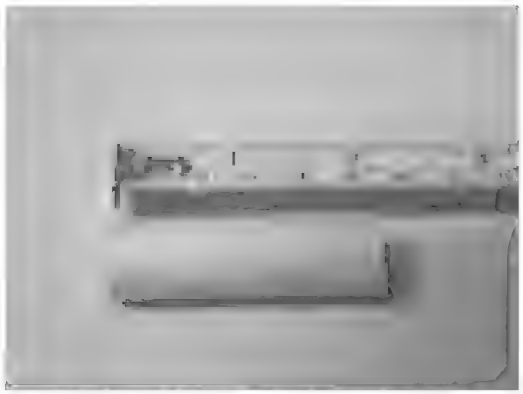


Figure 8-3: Now I have a 2-inch length of CPVC pipe.

Now prepare some of the nozzle clay described in the "NOZZLE CLAY" chapter and get your ramming tool that is described in the chapter "RAMMING TOOLS". After reading the ramming tool chapter I find that the ramming tool consists of a 3/8-inch dowel rod with the measurements marked on it.

Now stand the motor tube on end on a hard surface such as a concrete floor or steel block and pour some of the nozzle clay in the tube. I like to use an index card folded in half to pour the clay in.

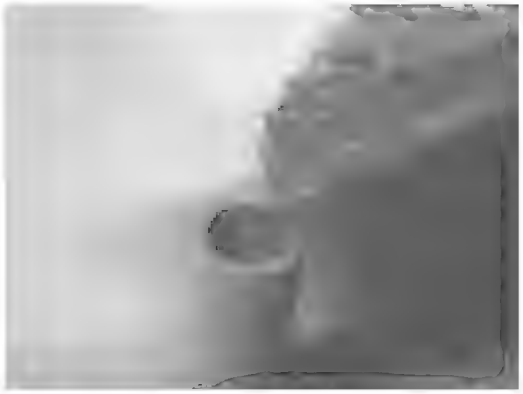


Figure 8-4: Pouring nozzle clay into the tube.

Just put a small about in and take your ramming tool and a hammer and slide the dowel into the CPVC pipe and smack the top of the dowel rod with a hammer a few times to pack the nozzle clay tightly into the tube. Keep adding nozzle clay and ramming it into the tube like this until you fill the bottom of the tube ½ inch with the clay. You can tell it is ½ of an inch when your rammer has the measure of 1-1/2 inches when it is

inserted up against the clay in the tube. I found this number by subtracting the thickness of the nozzle (from the diagram it says ½ inch) from the total length of the tube (2 inches).

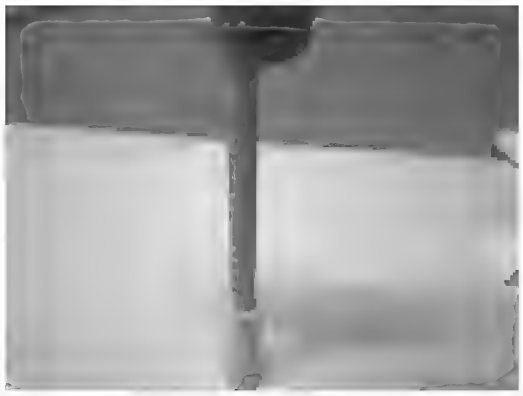


Figure 8-5: Ramming the nozzle clay into the bottom of the tube with a ramming tool and hammer.

You should now have a clay plug in the tube that should be very hard from ramming it. You can feel it and scratch it with your fingernail and make sure it doesn't crumble. If it crumbles then you either didn't ram it hard enough or your nozzle clay was too dry and needs a little water added to it. Don't over wet the clay though!

Figure 8-6: Rammed nozzle clay is hard to the touch and stays in the tube well.

Now you are ready to load the propellant. Make sure you are wearing your face shield! To load the propellant take your ready mixed propellant from the "PROPELLANT" chapter and pour some into the tube just like you did with the nozzle clay.

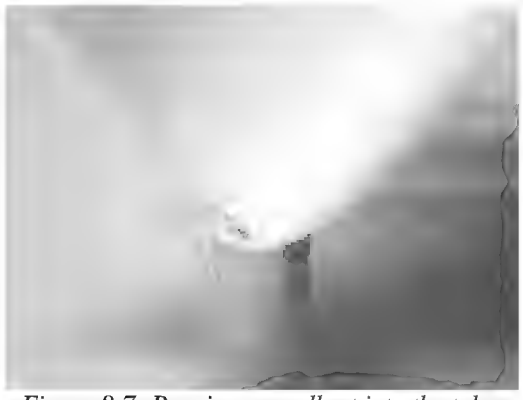


Figure 8-7: Pouring propellant into the tube.

Now ram the propellant into the tube just as you did with the nozzle clay and keep adding and ramming portions of the propellant until you read 1 inch on your rammer tool, so that means you have 1 inch of empty space in the tube left. I found this by looking at the diagram and seeing that the propellant section and nozzle section add up to 1 inch in length and I subtracted this from the total length of the tube, which gives me 1 inch.

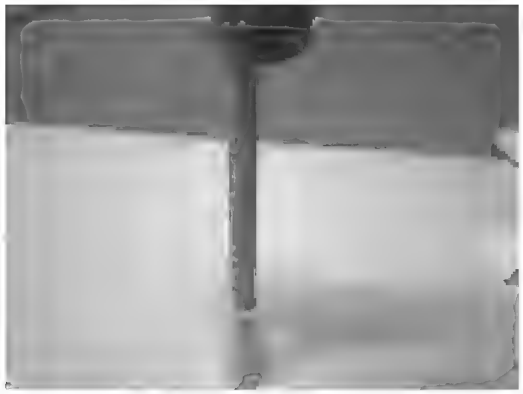


Figure 8-8: Ramming the propellant into the bottom of the tube with a ramming tool and hammer.

Pour in some more nozzle clay to cap off the rocket engine and ram it in just as you did with the other clay and nozzle until you read ½ inch on the ramming tool.

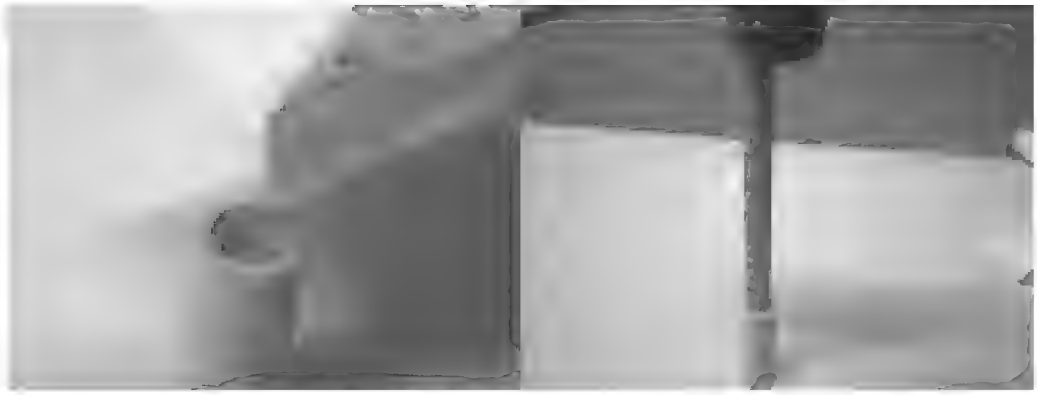


Figure 8-9: Pouring more nozzle clay into the tube and ramming it to cap off the top of the engine.

There should now be a ½ inch gap to the top of the clay on the front of the motor. This just allows for easier ramming for the extra length of the tube to help guide the ramming tool.

Figure 8-10: Top of the motor should have some space down to the clay.

Now you need to drill the nozzle and hollow core. Look at the diagram of the A7 engine and it shows a diameter of 5/64 inch for the nozzle hole and core. Get a 5/64 inch drill bit and turn it in by hand through the center of the clay at first to make the hole center and you can either keep turning it by hand or use a drill on low speed. Keep the drill on low speed to keep it from getting hot from the friction because we don't want it to ignite the propellant! Make sure you keep the drill bit clean as well from clay and propellant that may stick in the threads. Just go slowly and keep it cool and you should not have a problem. The ignition temperature is high for this propellant so it shouldn't ignite from the drilling but please don't press your luck and drill it too quickly because it may ignite. Also it is a good idea not to hold the motor while drilling. Instead place it in a vice or clamp to drill it. Also don't stand directly in front of the engine or behind it. Stand off to the side of it.

Figure 8-11: Drilling the nozzle hole and hollow core for the engine.

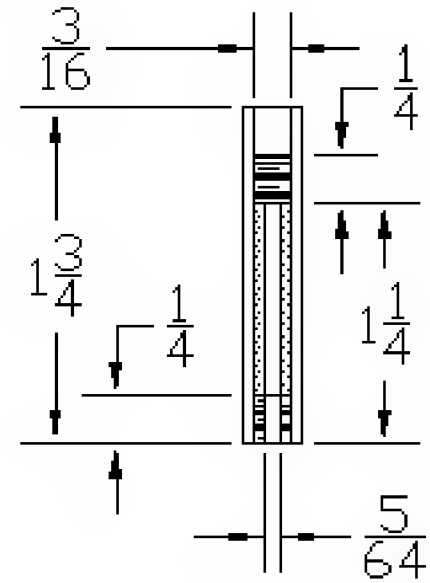
Drill into the motor 1-inch since that is what the diagram specifies the total core length to be. You can mark your drill bit with a small piece of tape to make sure you don't go past this length. You now have a completed rocket motor ready to be prepped for firing.

Figure 8-12: Completed rocket motor with nozzle and core drilled.

See the chapters on storage and preparing the engines to fire and stick rockets for information of flying these engines. Make sure you store these as specified in the "STORAGE" chapter right away if you do not plan on firing them right away. The propellant is hydroscopic and will draw moisture, which will render the rocket motor useless in a short time.

MOTOR DESIGNS AND DATA

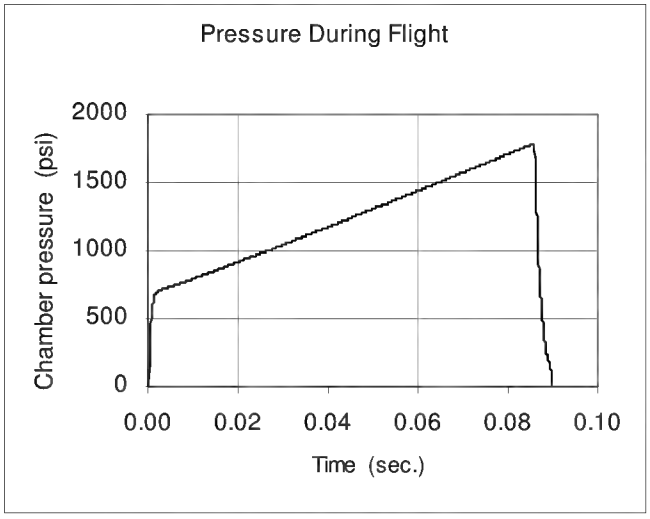
1/4A6 MOTOR DESIGN



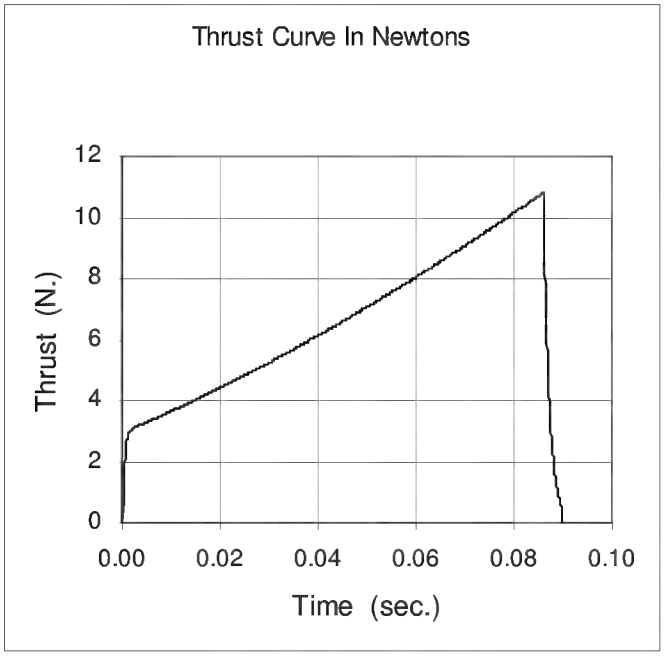
1/4A6 MOTOR DATA

Motor Classification: 1/4A
Weight of Propellant: .678 g

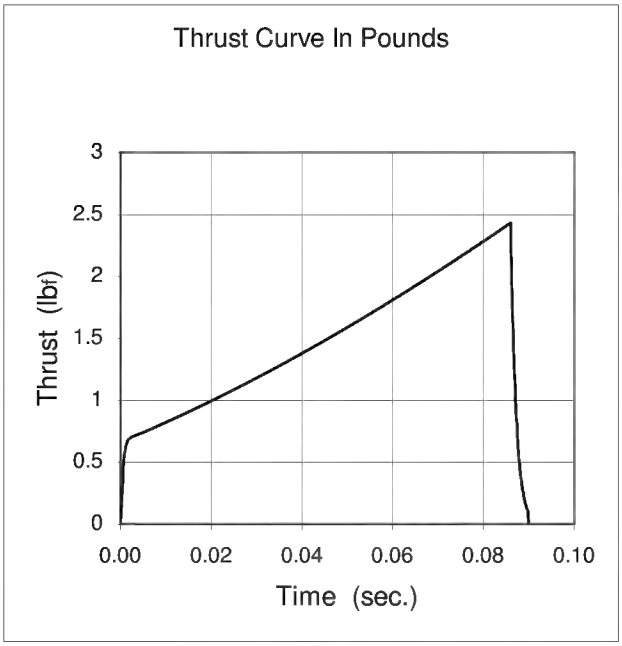
Total Impulse: .575 N-sec.
Specific Impulse Delivered: 86.4 sec.



Max Pressure: 1801 psi
Time of Burn: .086 sec
Time of Thrust: .090 sec

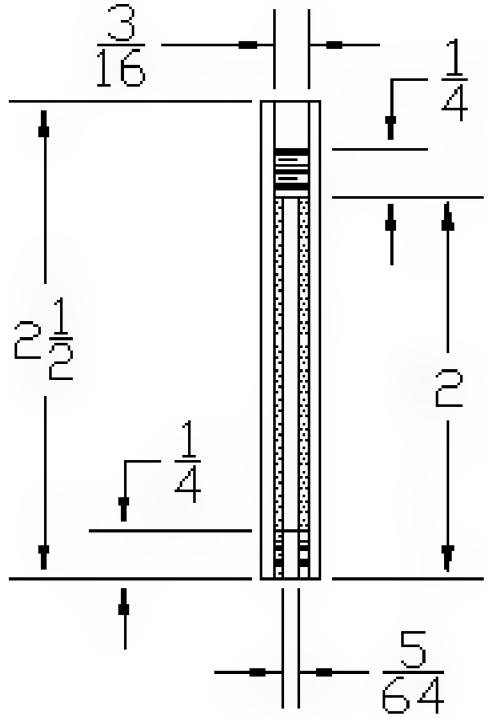


Max Thrust: 10.81 N
Average Thrust: 6.39 N



Max Thrust: 2.43 lbs
Average Thrust: 1.44 lbs

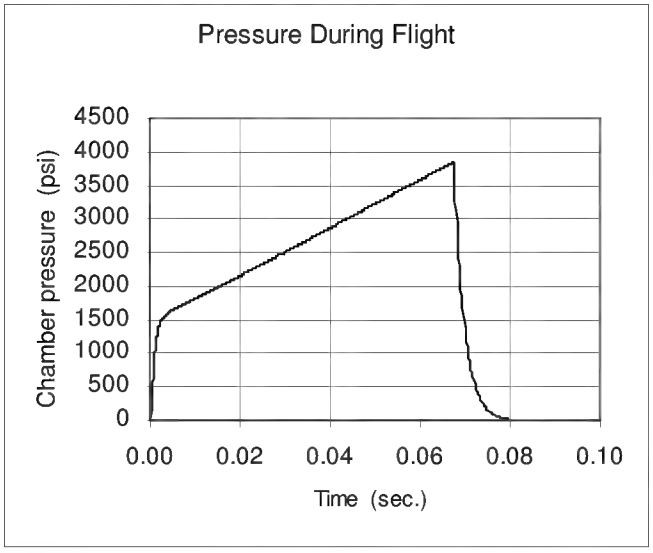
1/2A13 MOTOR DESIGN



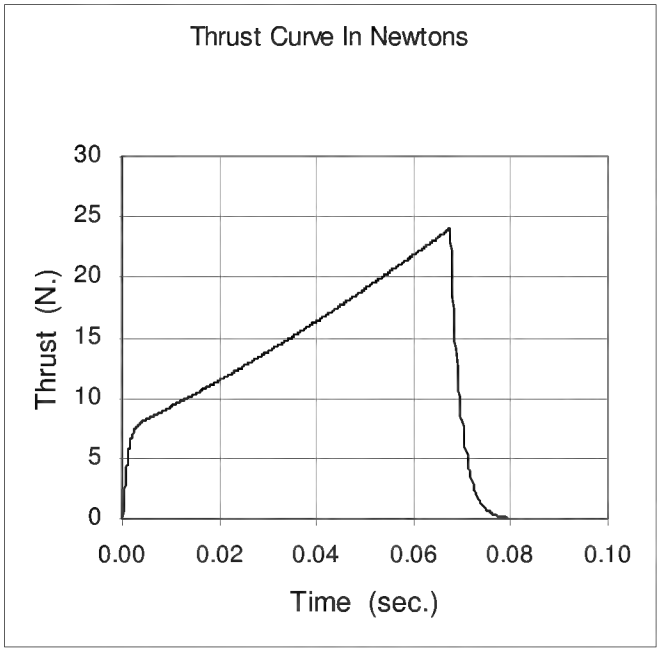
1/2A13 MOTOR DATA

Motor Classification: 1/2A
Weight of Propellant: 1.187 g

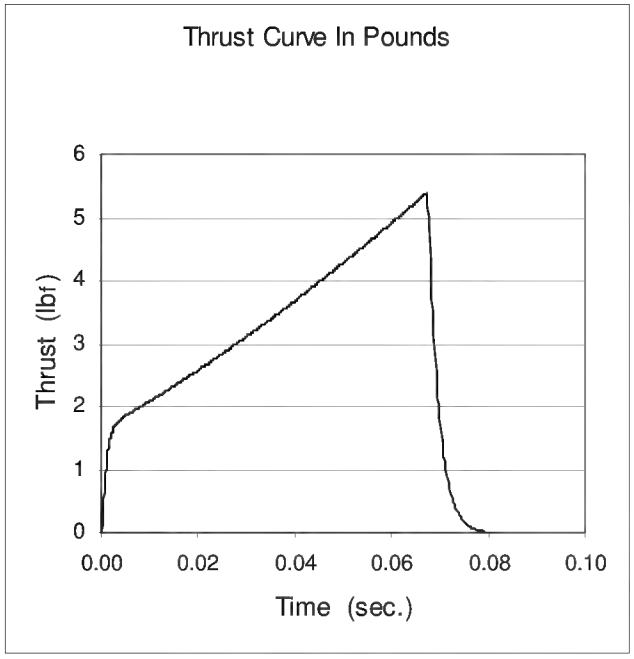
Total Impulse: 1.061 N-sec.
Specific Impulse Delivered: 91.2 sec.



Max Pressure: 3858 psi
Time of Burn: .067 sec
Time of Thrust: .079 sec

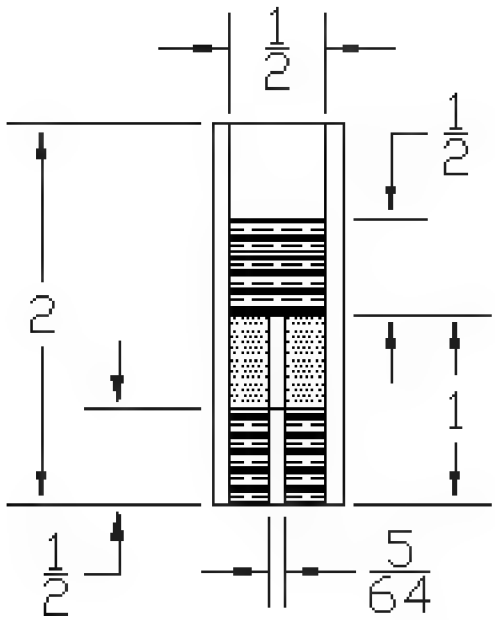


Max Thrust: 24.02 N
Average Thrust: 13.37 N



Max Thrust: 5.40 lbs
Average Thrust: 3.01 lbs

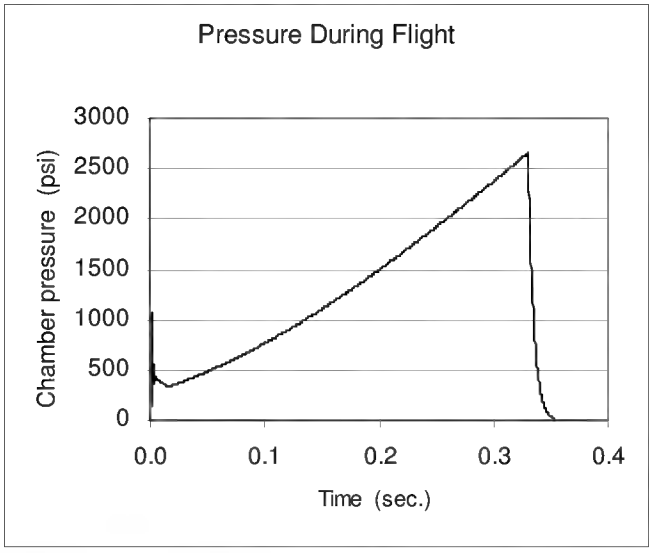
A7 MOTOR DESIGN



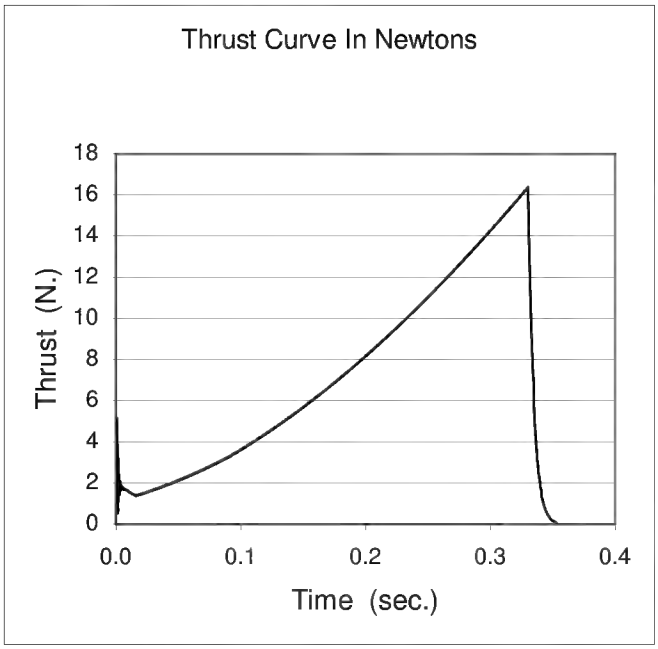
A7 MOTOR DATA

Motor Classification: A
Weight of Propellant: 2.846 g

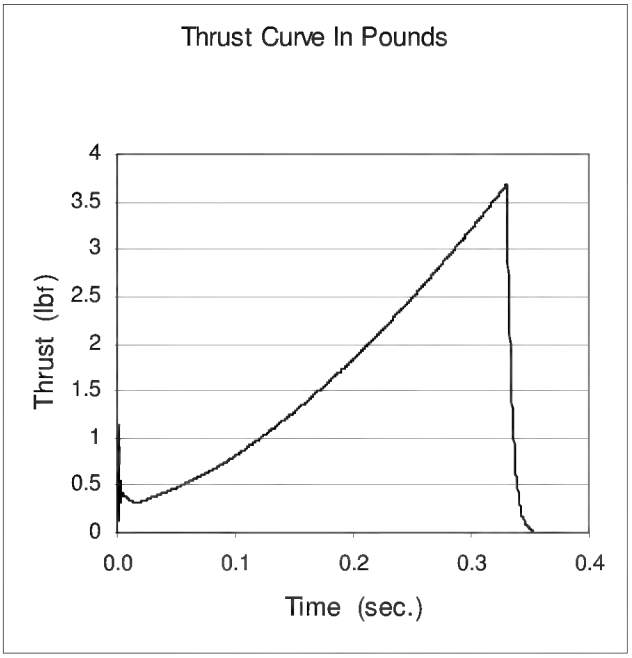
Total Impulse: 2.45 N-sec.
Specific Impulse Delivered: 87.7 sec.



Max Pressure: 2669 psi
Time of Burn: .330 sec
Time of Thrust: .353 sec

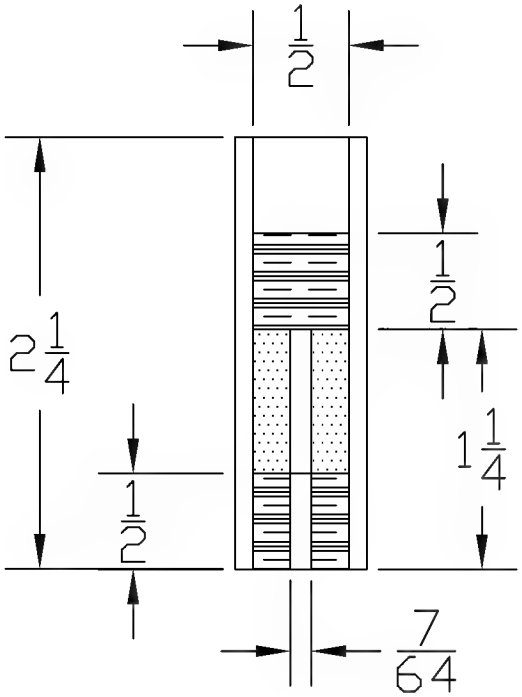


Max Thrust: 16.38 N
Average Thrust: 6.94 N



Max Thrust: 3.68 lbs
Average Thrust: 1.56 lbs

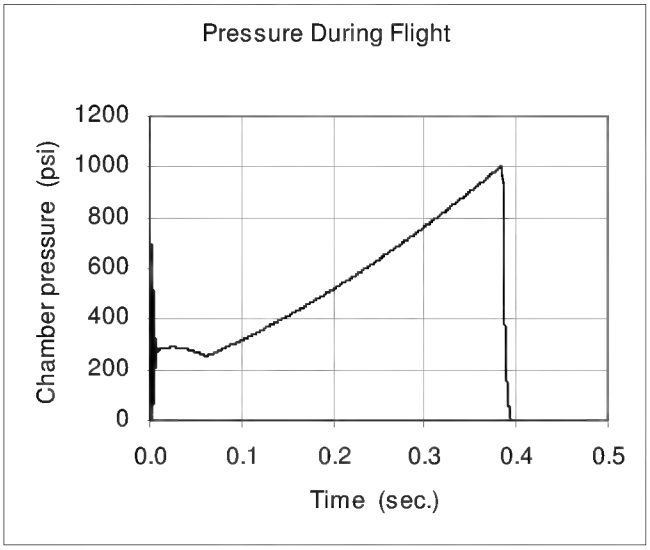
B8 MOTOR DESIGN



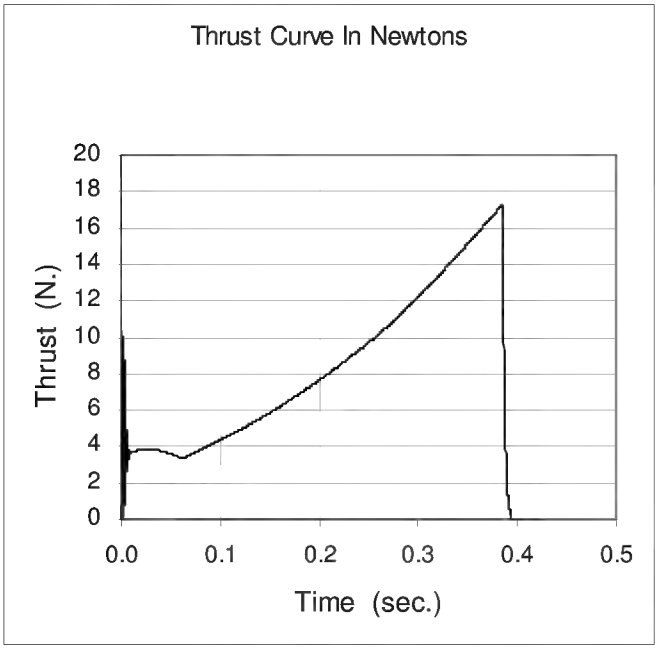
B8 MOTOR DATA

Motor Classification: B
Weight of Propellant: 4.17 g

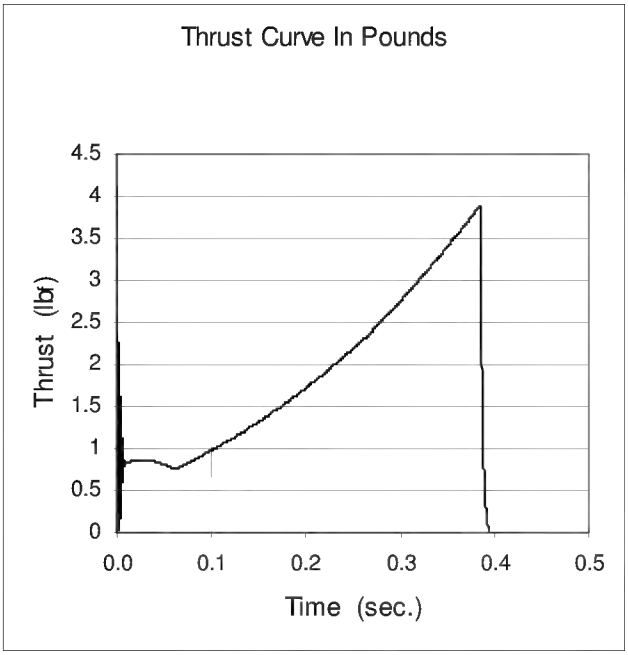
Total Impulse: 3.24 N-sec.
Specific Impulse Delivered: 79.2 sec.



Max Pressure: 1021 psi
Time of Burn: .385 sec
Time of Thrust: .394 sec

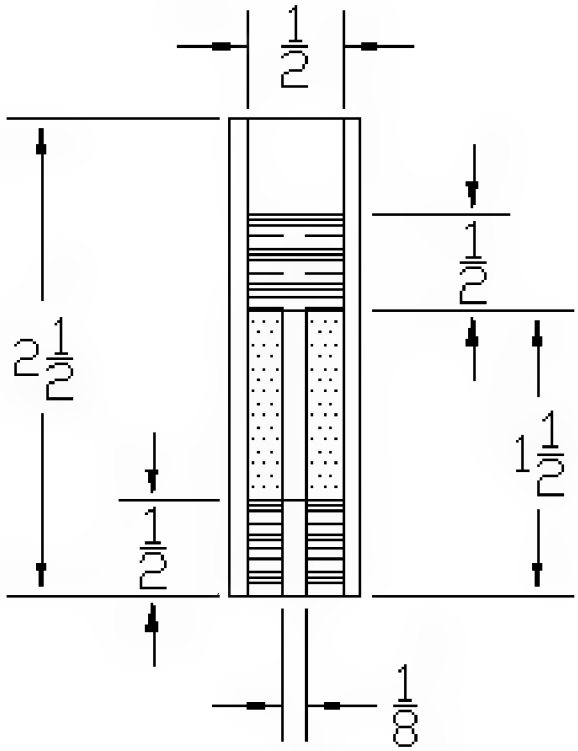


Max Thrust: 17.30 N
Average Thrust: 8.21 N



Max Thrust: 3.89 lbs
Average Thrust: 1.85 lbs

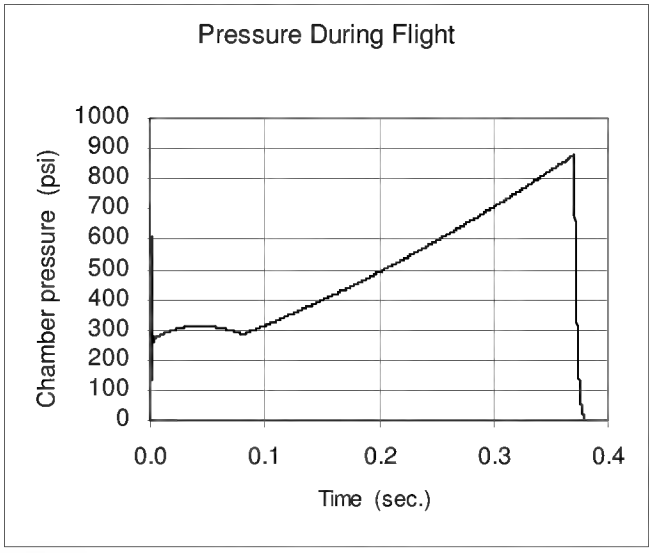
B11 MOTOR DESIGN



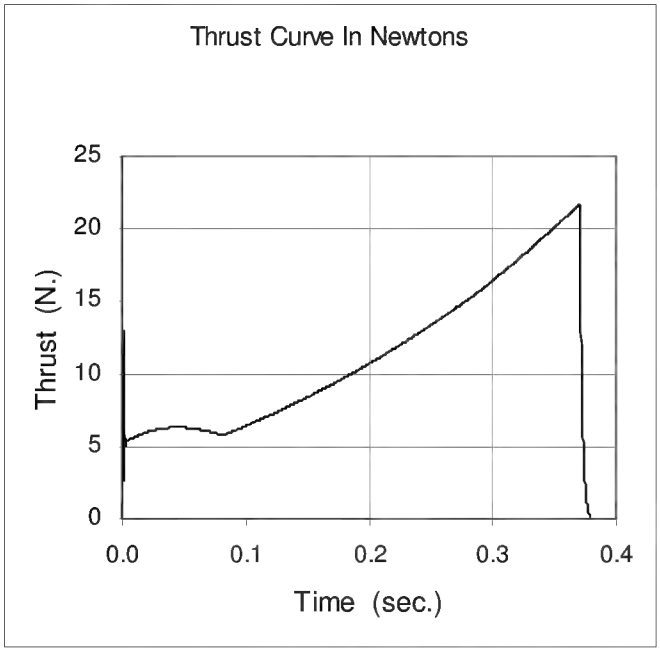
B11 MOTOR DATA

Motor Classification: B
Weight of Propellant: 5.47 g

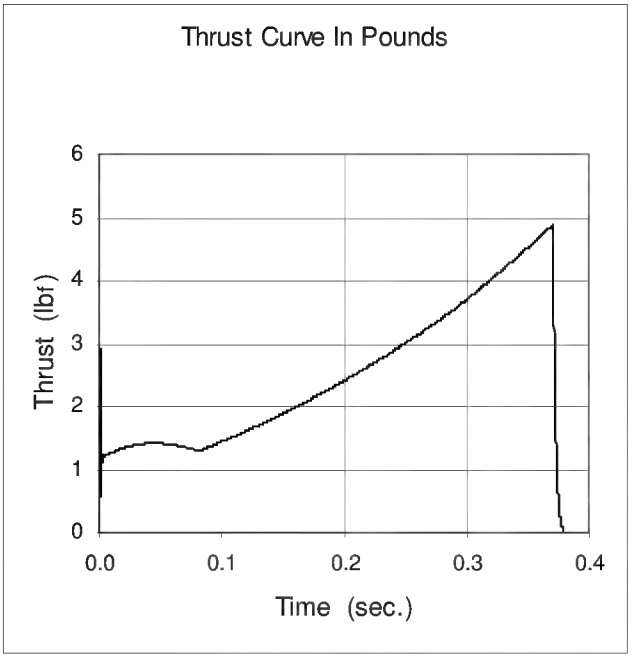
Total Impulse: 4.174 N-sec.
Specific Impulse Delivered: 77.8 sec.



Max Pressure: 893 psi
Time of Burn: .371 sec
Time of Thrust: .378 sec

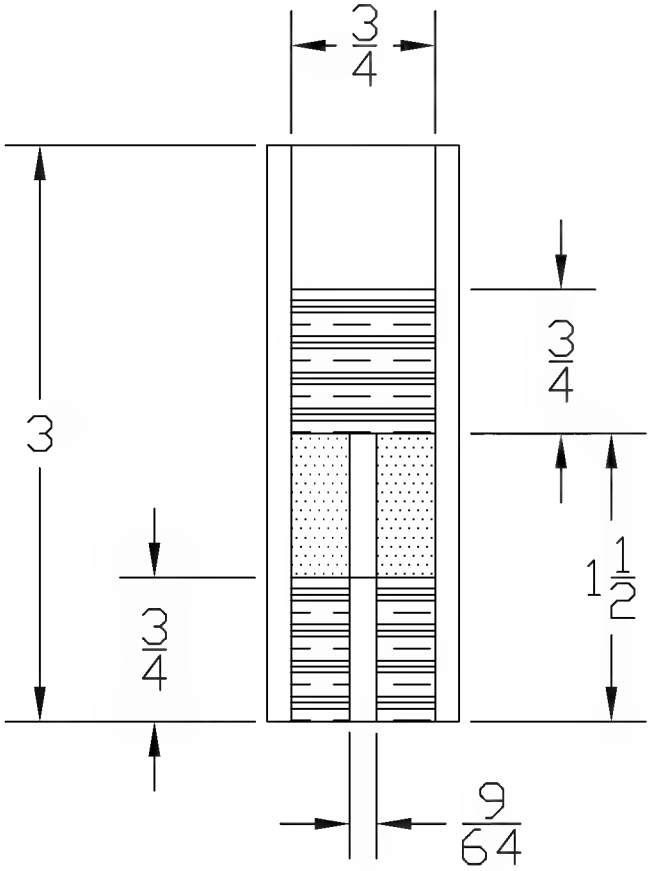


Max Thrust: 21.71 N
Average Thrust: 11.03 N



Max Thrust: 4.88 lbs
Average Thrust: 2.48 lbs

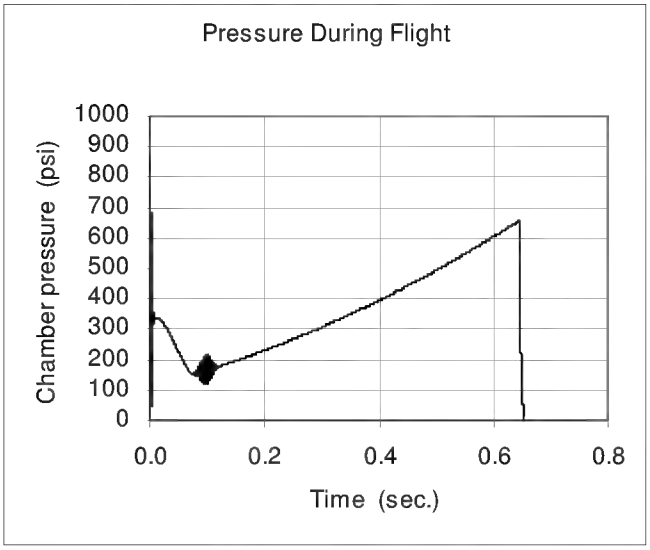
C11 MOTOR DESIGN



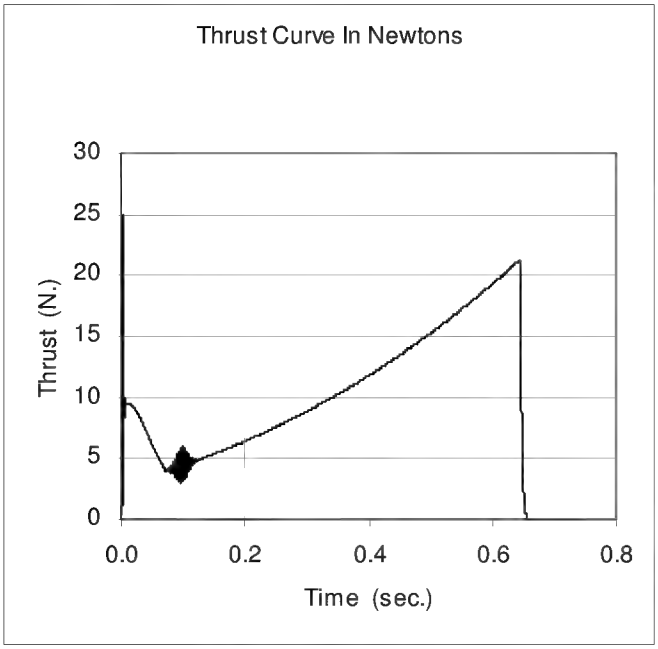
C11 MOTOR DATA

Motor Classification: C
Weight of Propellant: 9.50 g

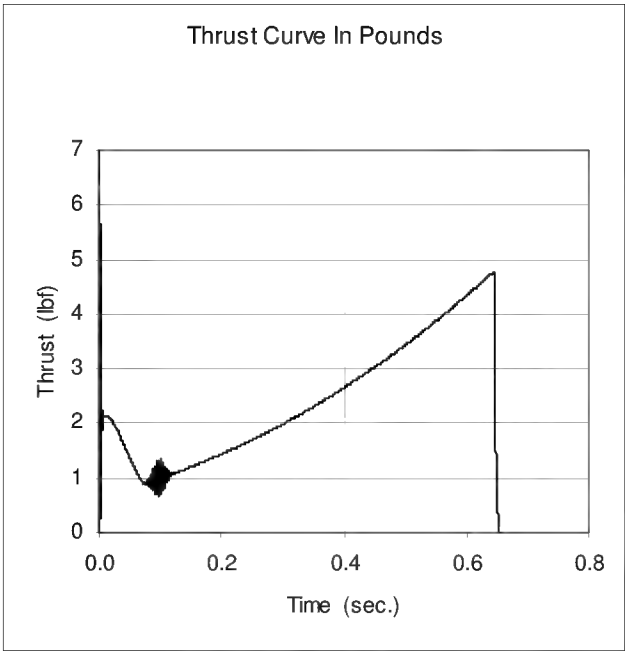
Total Impulse: 7.01 N-sec.
Specific Impulse Delivered: 75.2 sec.



Max Pressure: 888 psi
Time of Burn: .645 sec
Time of Thrust: .654 sec

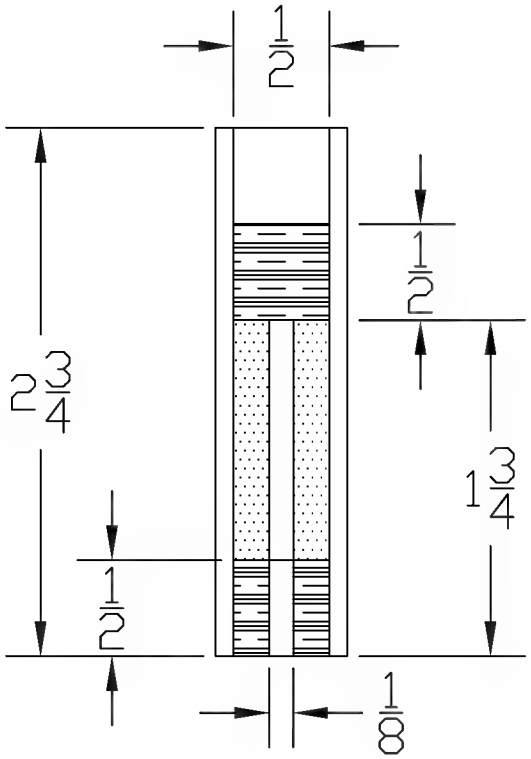


Max Thrust: 27.36 N
Average Thrust: 10.72 N



Max Thrust: 6.15 lbs
Average Thrust: 2.41 lbs

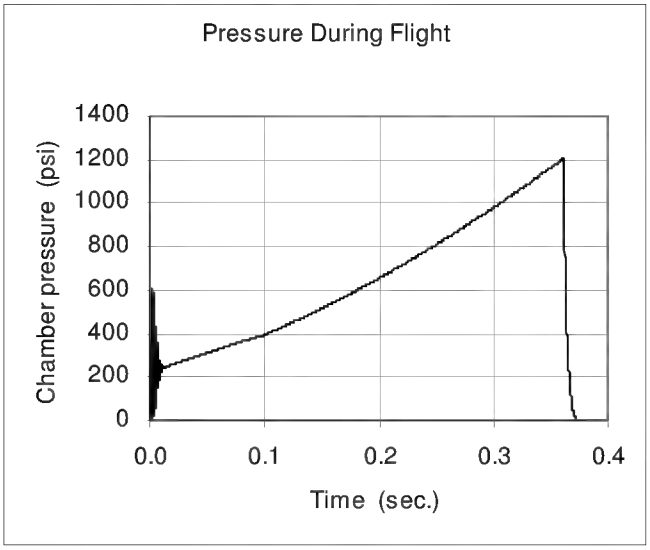
C15 MOTOR DESIGN



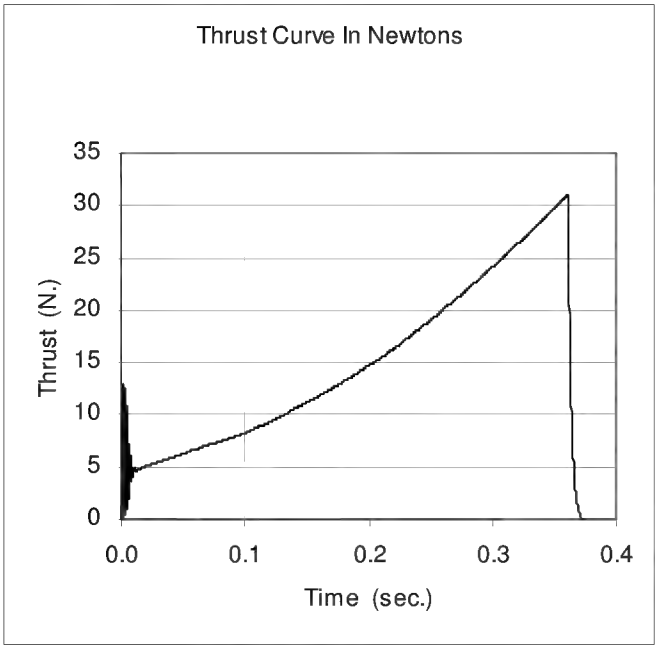
C15 MOTOR DATA

Motor Classification: C
Weight of Propellant: 6.84 g

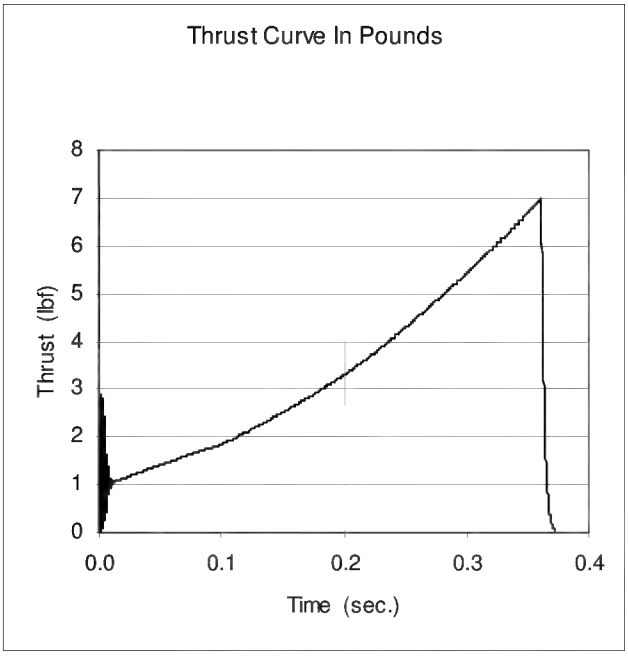
Total Impulse: 5.43 N-sec.
Specific Impulse Delivered: 81.0 sec.



Max Pressure: 1220 psi
Time of Burn: .361 sec
Time of Thrust: .372 sec

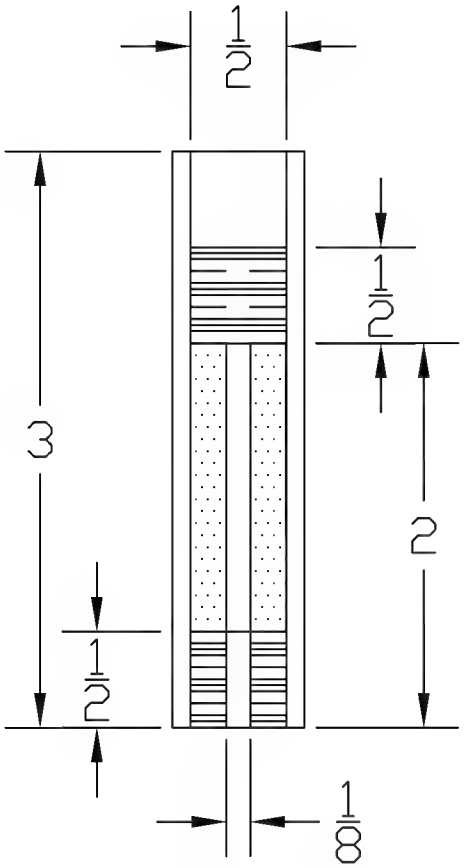


Max Thrust: 31.03 N
Average Thrust: 14.61 N



Max Thrust: 6.97 lbs
Average Thrust: 3.28 lbs

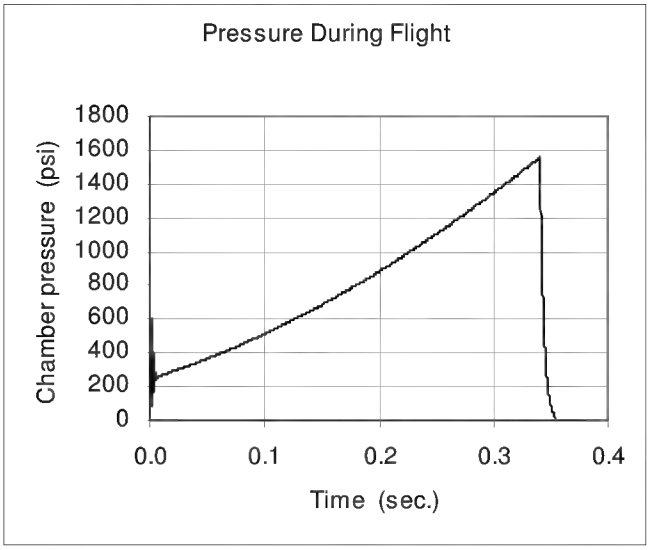
C19 MOTOR DESIGN



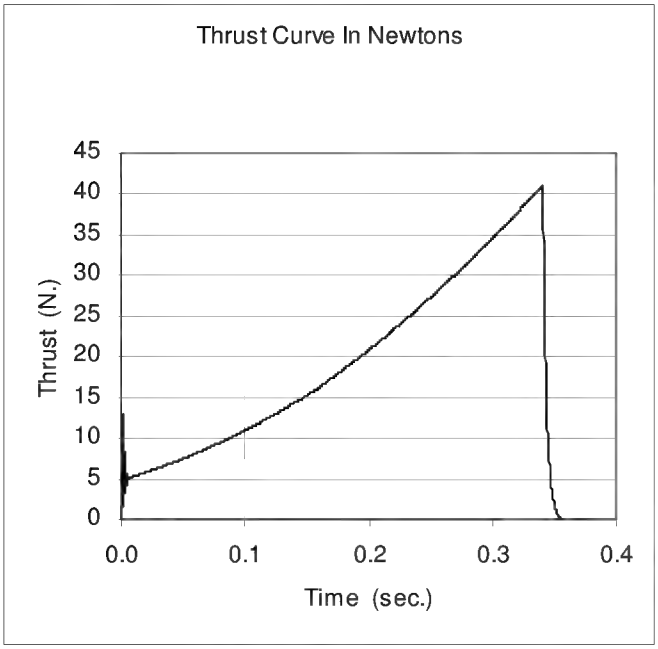
C19 MOTOR DATA

Motor Classification: C
Weight of Propellant: 8.01 g

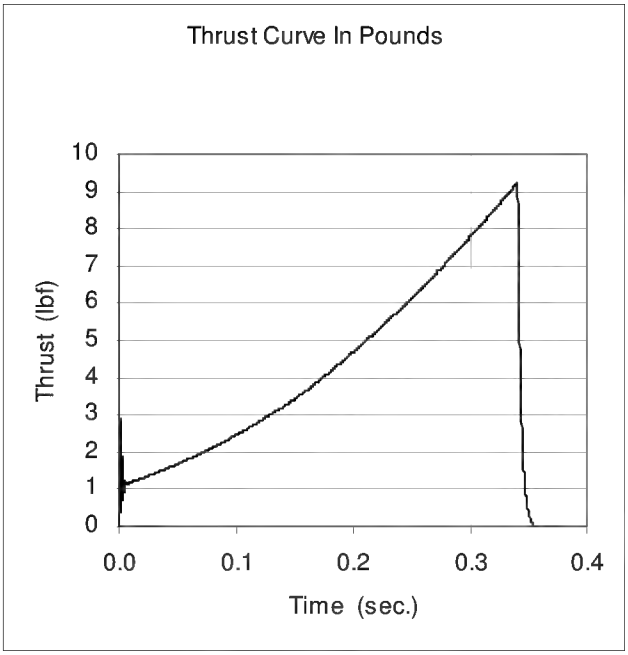
Total Impulse: 6.70 N-sec.
Specific Impulse Delivered: 83.3 sec.



Max Pressure: 1572 psi
Time of Burn: .341 sec
Time of Thrust: .354 sec

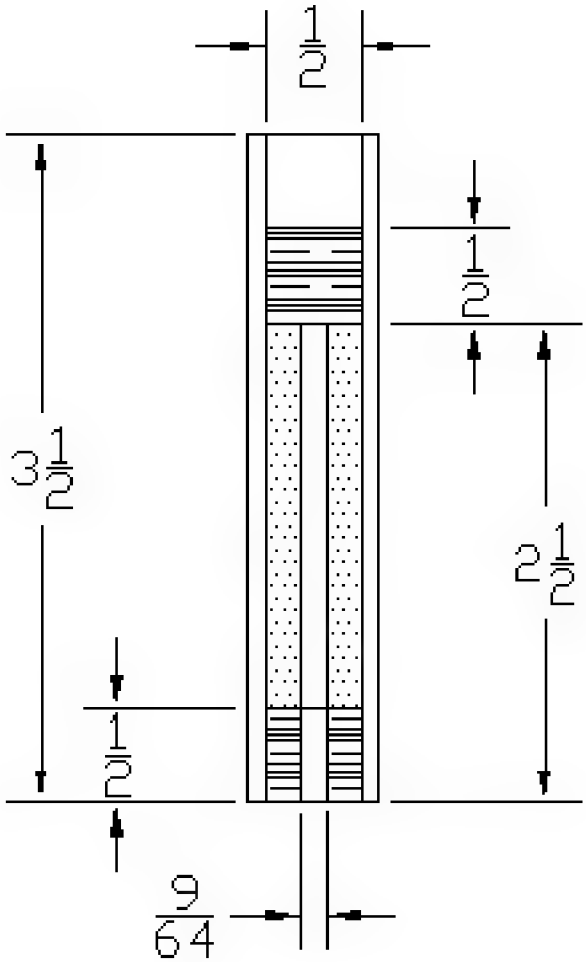


Max Thrust: 41.07 N
Average Thrust: 18.92 N



Max Thrust: 9.23 lbs
Average Thrust: 4.25 lbs

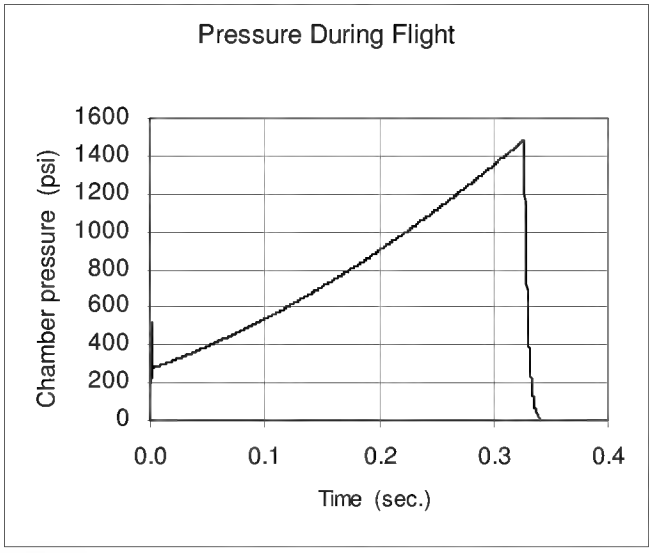
C26 MOTOR DESIGN



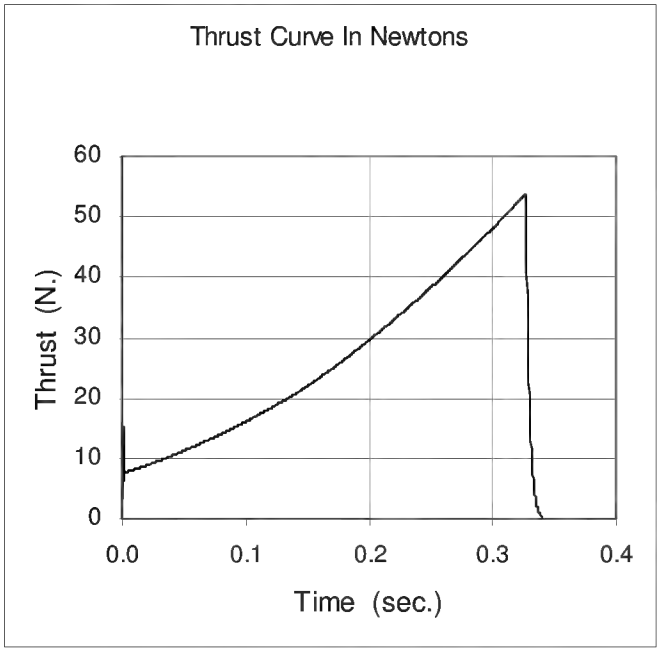
C26 MOTOR DATA

Motor Classification: C
Weight of Propellant: 10.747 g

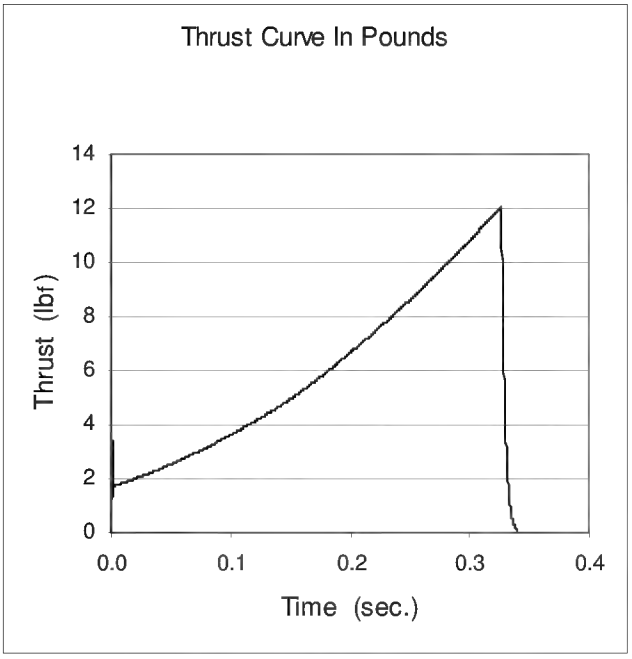
Total Impulse: 8.74 N-sec.
Specific Impulse Delivered: 82.9 sec.



Max Pressure: 1499 psi
Time of Burn: .327 sec
Time of Thrust: .340 sec

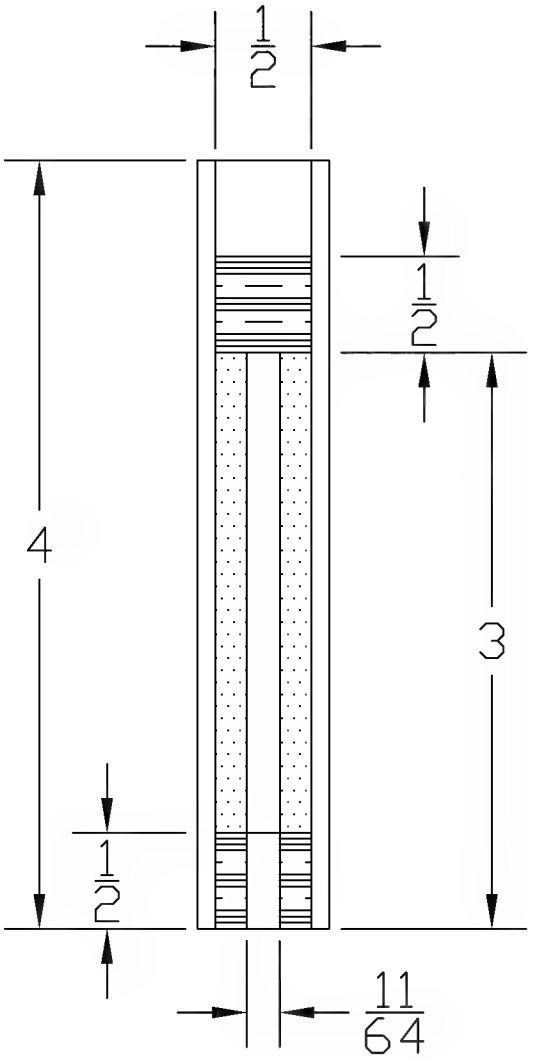


Max Thrust: 53.78 N
Average Thrust: 25.73 N



Max Thrust: 12.09 lbs
Average Thrust: 5.78 lbs

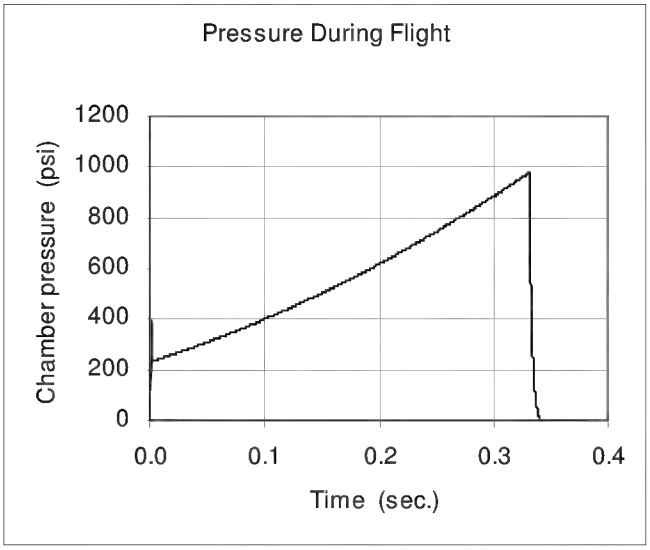
C29 MOTOR DESIGN



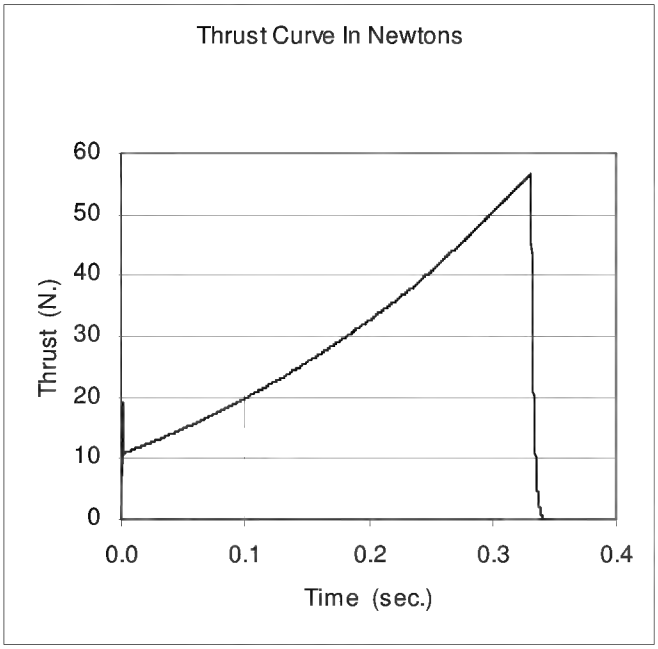
C29 MOTOR DATA

Motor Classification: C
Weight of Propellant: 12.86 g

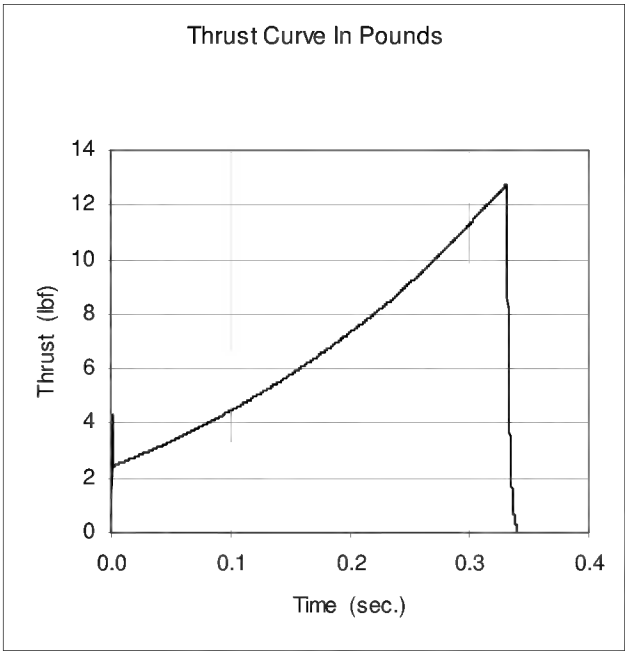
Total Impulse: 9.95 N-sec.
Specific Impulse Delivered: 78.9 sec.



Max Pressure: 991 psi
Time of Burn: .331 sec
Time of Thrust: .340 sec

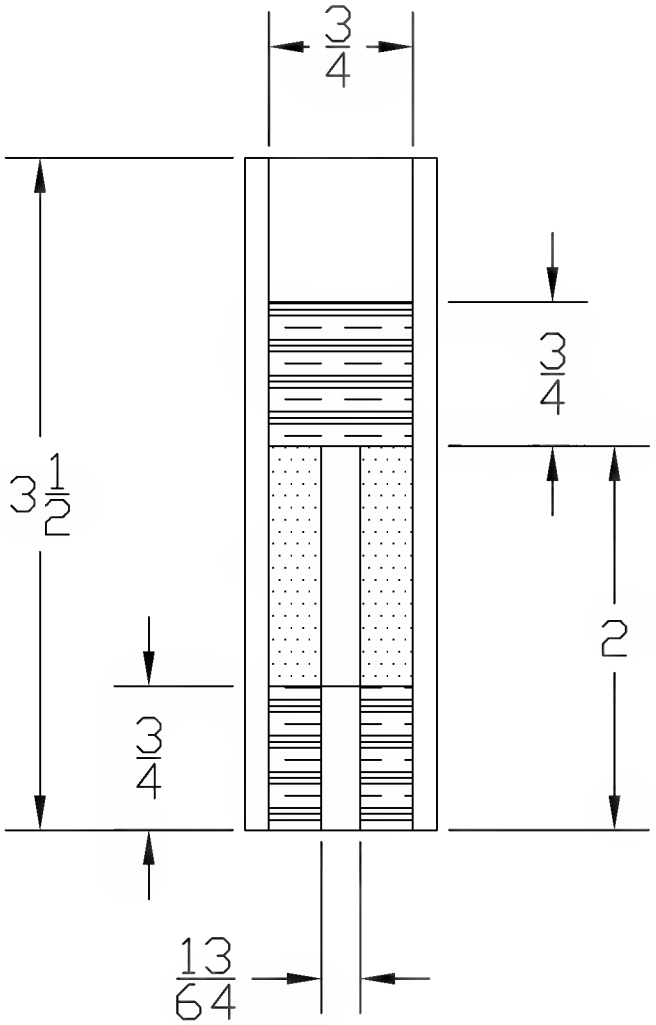


Max Thrust: 56.72 N
Average Thrust: 29.28 N



Max Thrust: 12.75 lbs
Average Thrust: 6.58 lbs

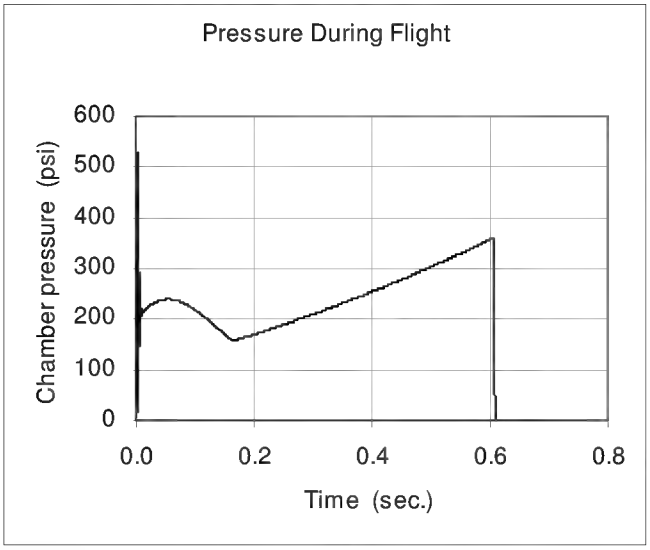
D18 MOTOR DESIGN



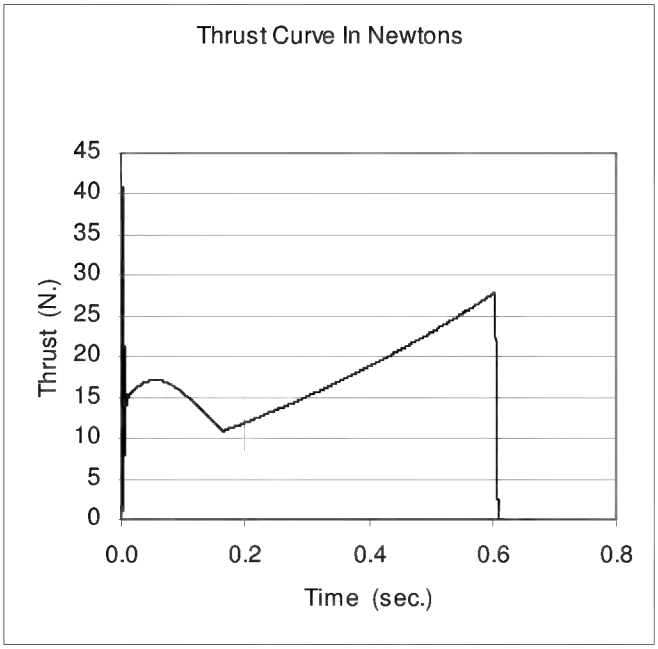
D18 MOTOR DATA

Motor Classification: D
Weight of Propellant: 15.21 g

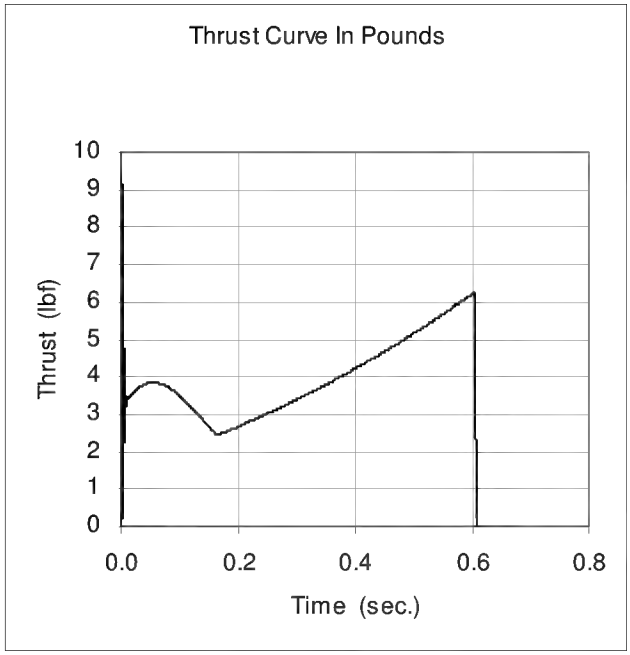
Total Impulse: 10.72 N-sec.
Specific Impulse Delivered: 71.9 sec.



Max Pressure: 561 psi
Time of Burn: .605 sec
Time of Thrust: .610 sec

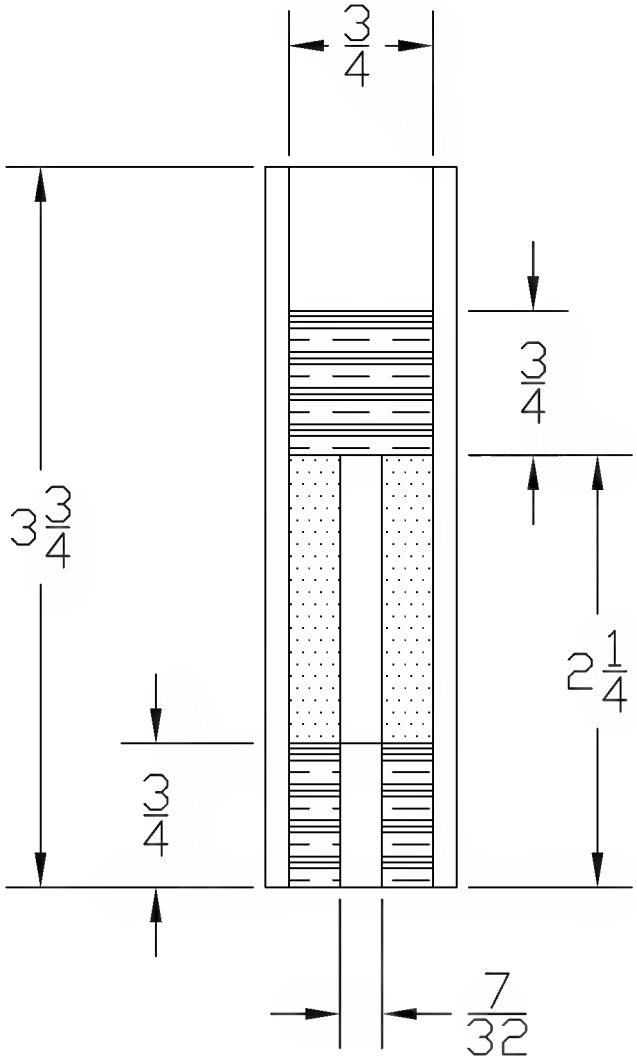


Max Thrust: 42.07 N
Average Thrust: 17.58 N



Max Thrust: 9.46 lbs
Average Thrust: 3.95 lbs

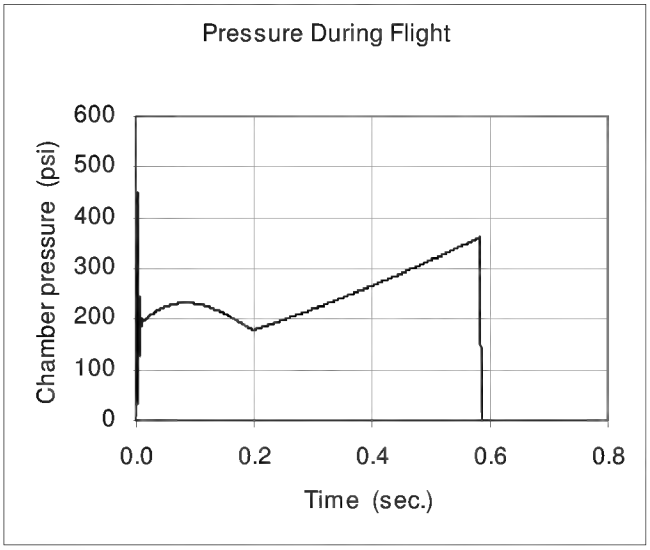
D22 MOTOR DESIGN



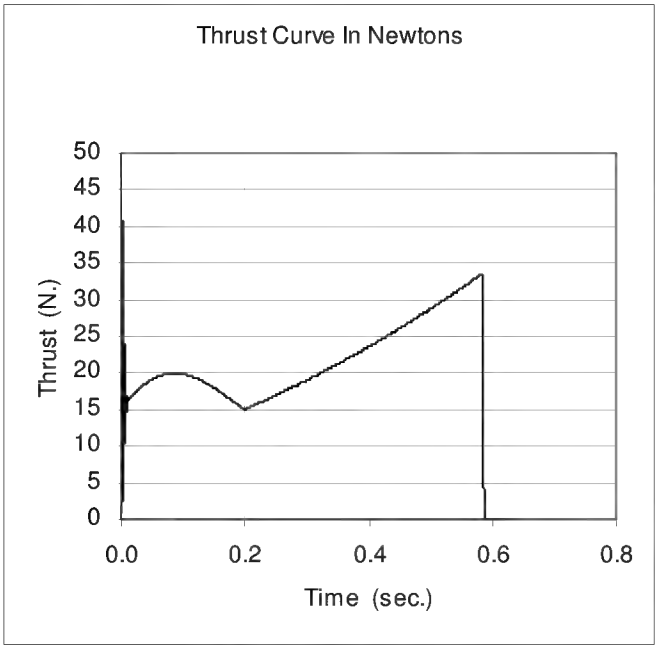
D22 MOTOR DATA

Motor Classification: D
Weight of Propellant: 18.02 g

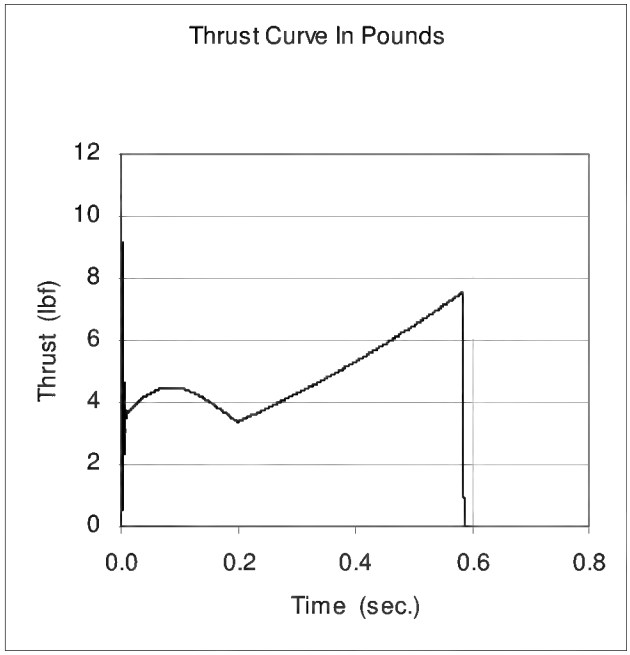
Total Impulse: 12.72 N-sec.
Specific Impulse Delivered: 72.0 sec.



Max Pressure: 507 psi
Time of Burn: .583 sec
Time of Thrust: .588 sec

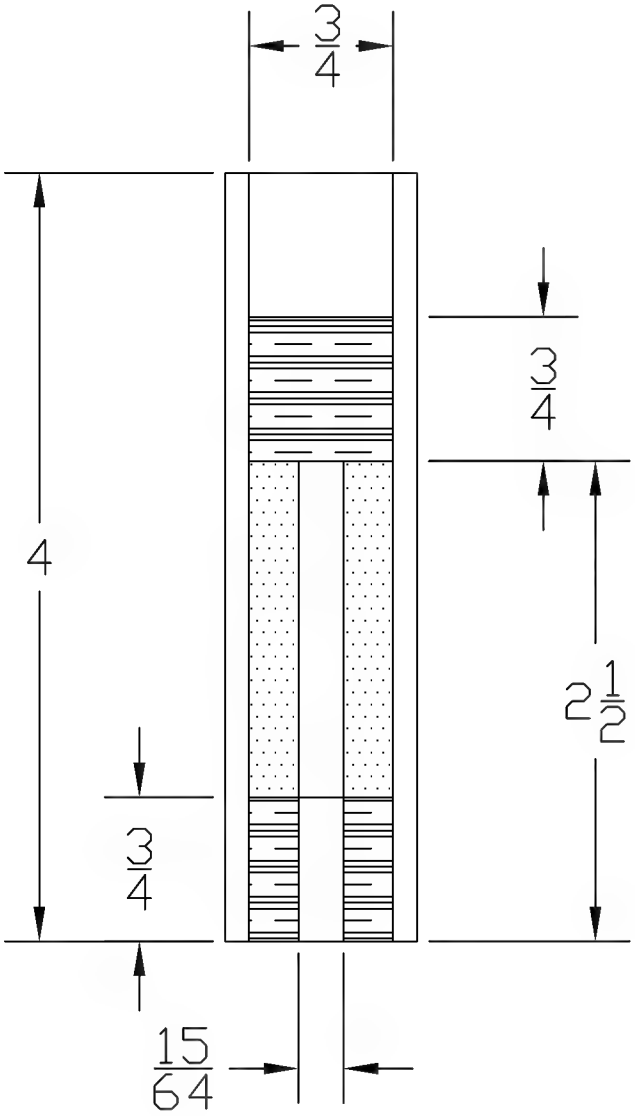


Max Thrust: 45.12 N
Average Thrust: 21.63 N



Max Thrust: 10.14 lbs
Average Thrust: 4.86 lbs

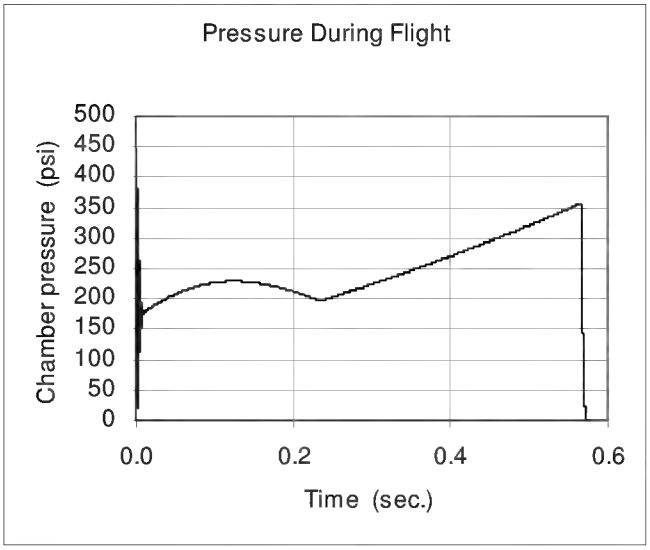
D26 MOTOR DESIGN



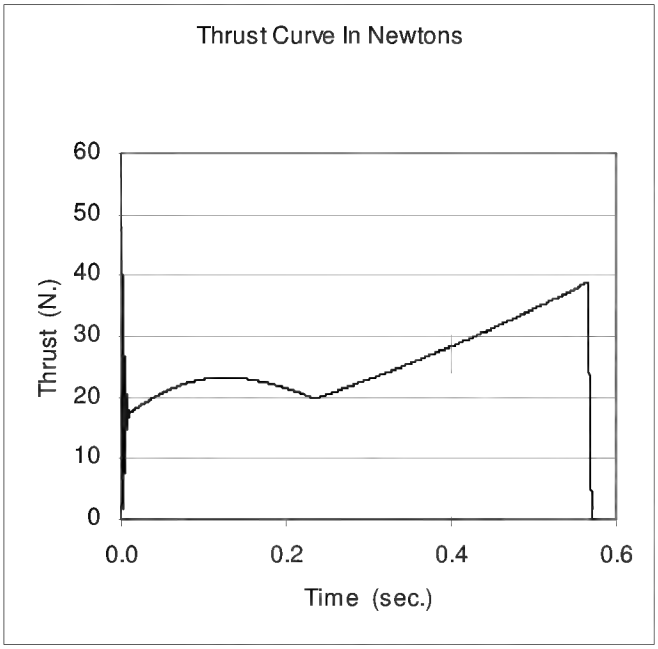
D26 MOTOR DATA

Motor Classification: D
Weight of Propellant: 20.73 g

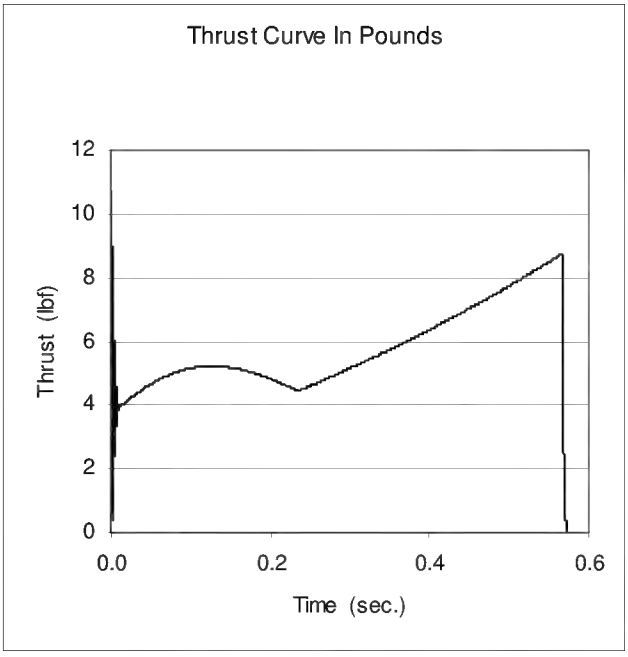
Total Impulse: 14.62 N-sec.
Specific Impulse Delivered: 71.9 sec.



Max Pressure: 461 psi
Time of Burn: .567 sec
Time of Thrust: .571 sec

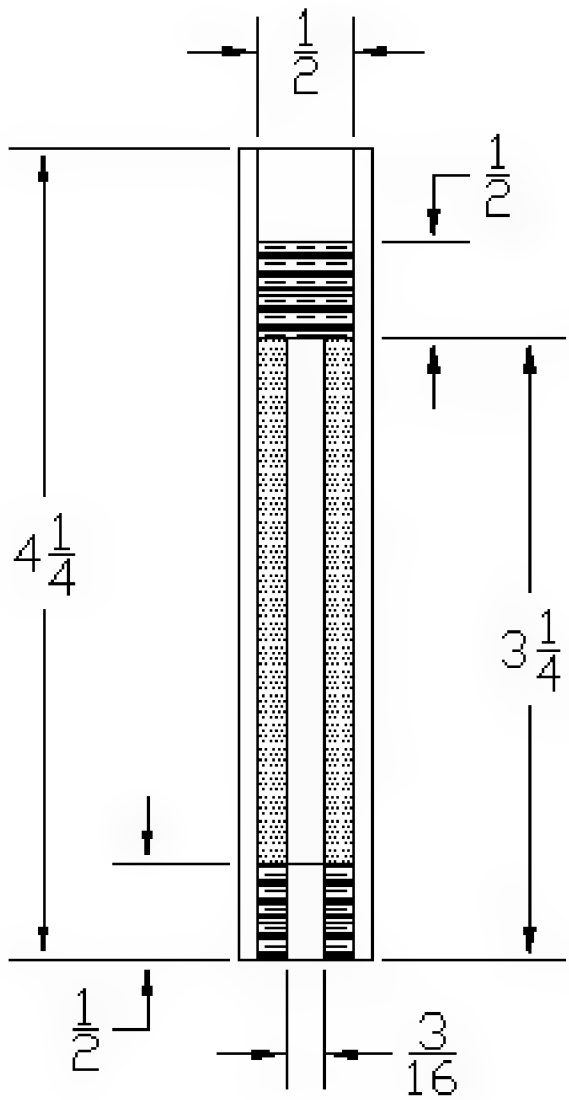


Max Thrust: 47.87 N
Average Thrust: 25.60 N



Max Thrust: 10.76 lbs
Average Thrust: 5.75 lbs

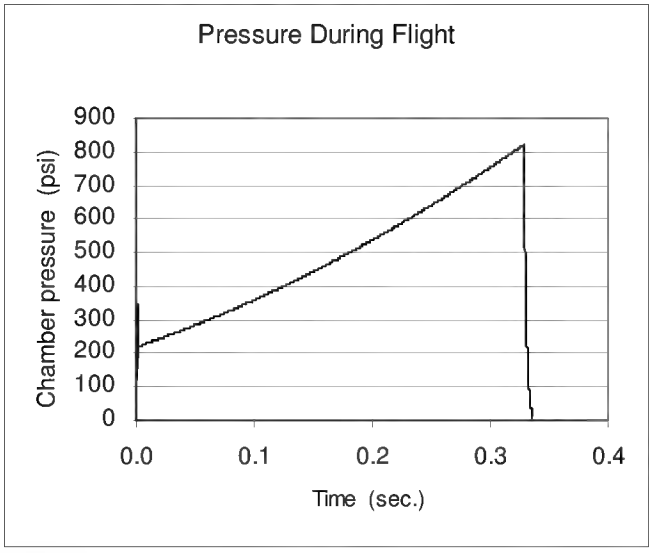
D31 MOTOR DESIGN



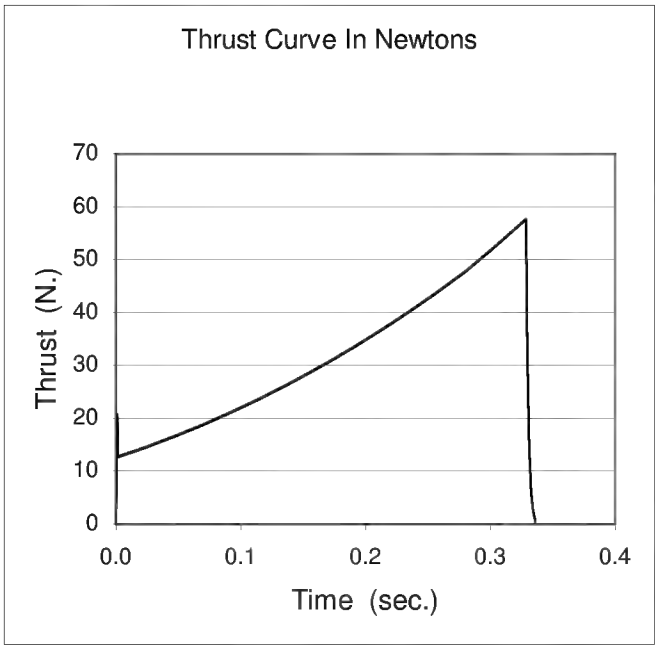
D31 MOTOR DATA

Motor Classification: D
Weight of Propellant: 13.79 g

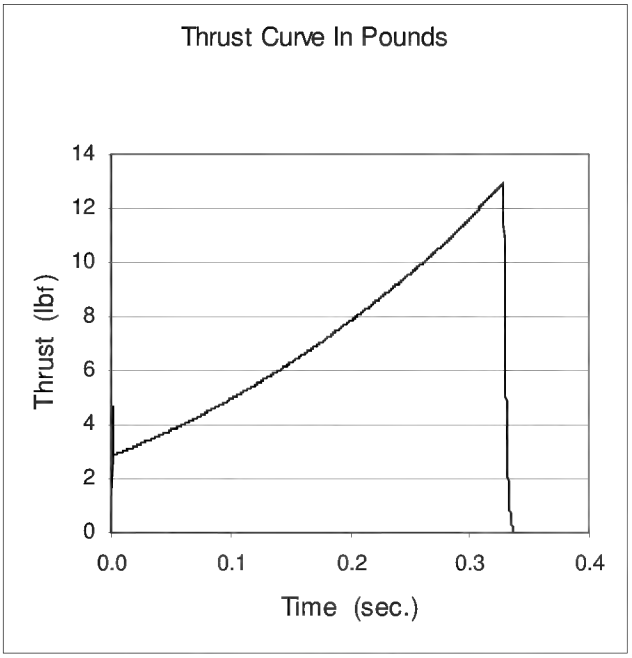
Total Impulse: 10.45 N-sec.
Specific Impulse Delivered: 77.3 sec.



Max Pressure: 836 psi
Time of Burn: .329 sec
Time of Thrust: .336 sec

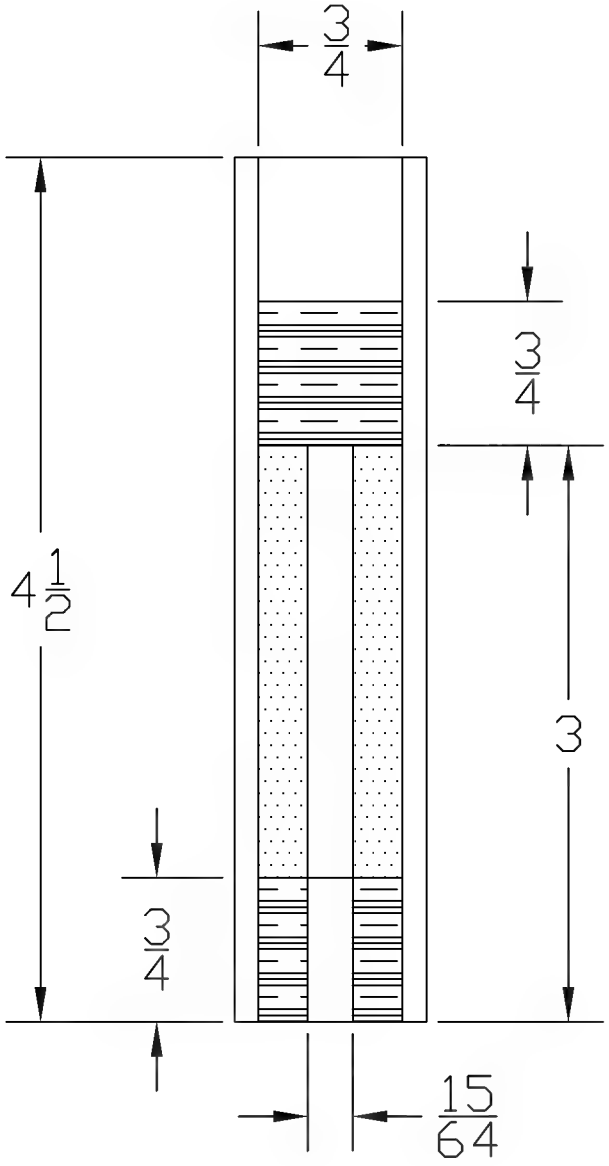


Max Thrust: 57.66 N
Average Thrust: 31.12 N



Max Thrust: 12.96 lbs
Average Thrust: 7.00 lbs

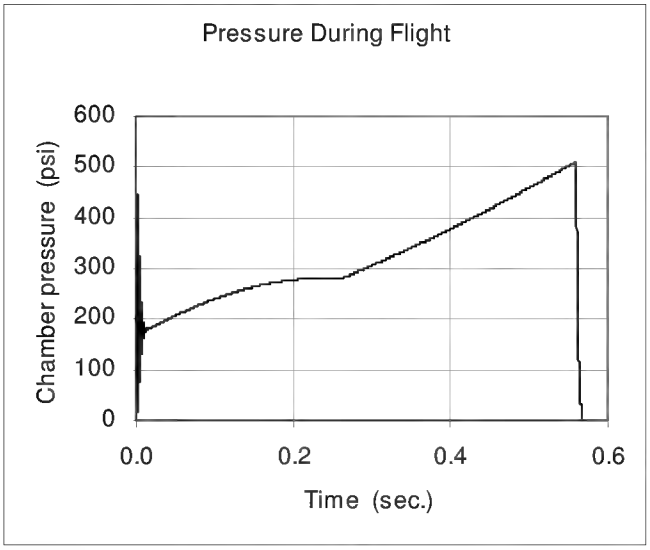
D34 MOTOR DESIGN



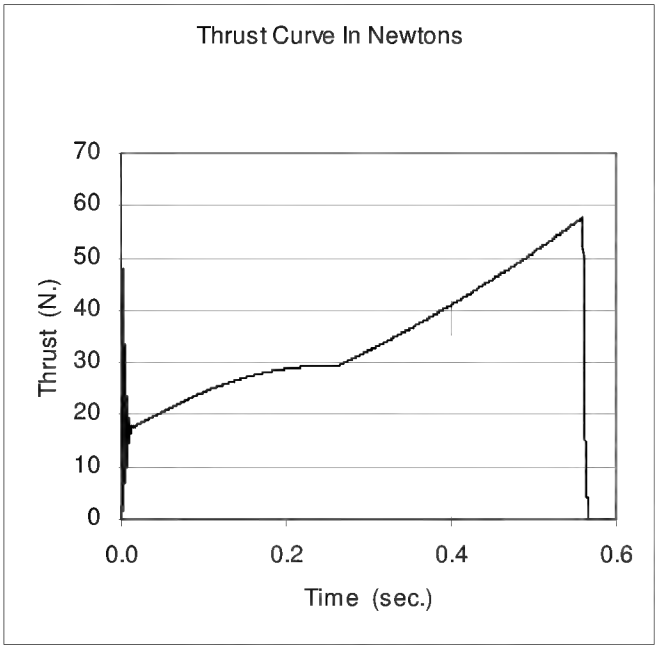
D34 MOTOR DATA

Motor Classification: D
Weight of Propellant: 26.66 g

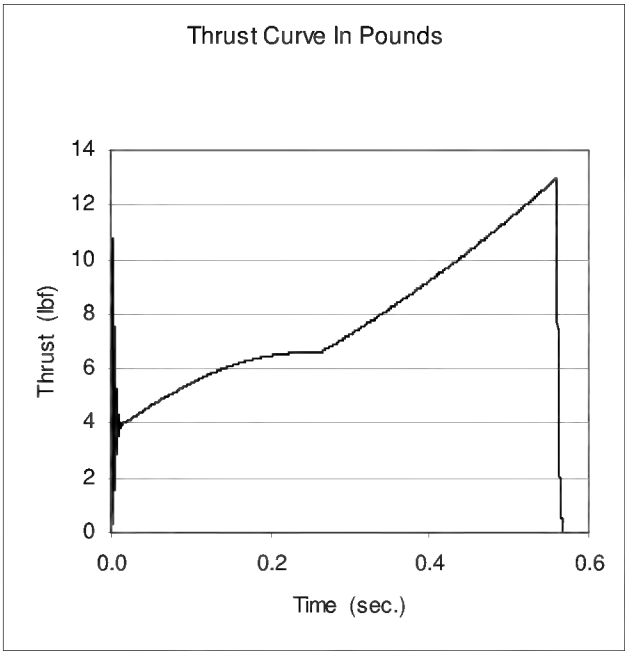
Total Impulse: 19.34 N-sec.
Specific Impulse Delivered: 74.0 sec.



Max Pressure: 525 psi
Time of Burn: .560 sec
Time of Thrust: .567 sec

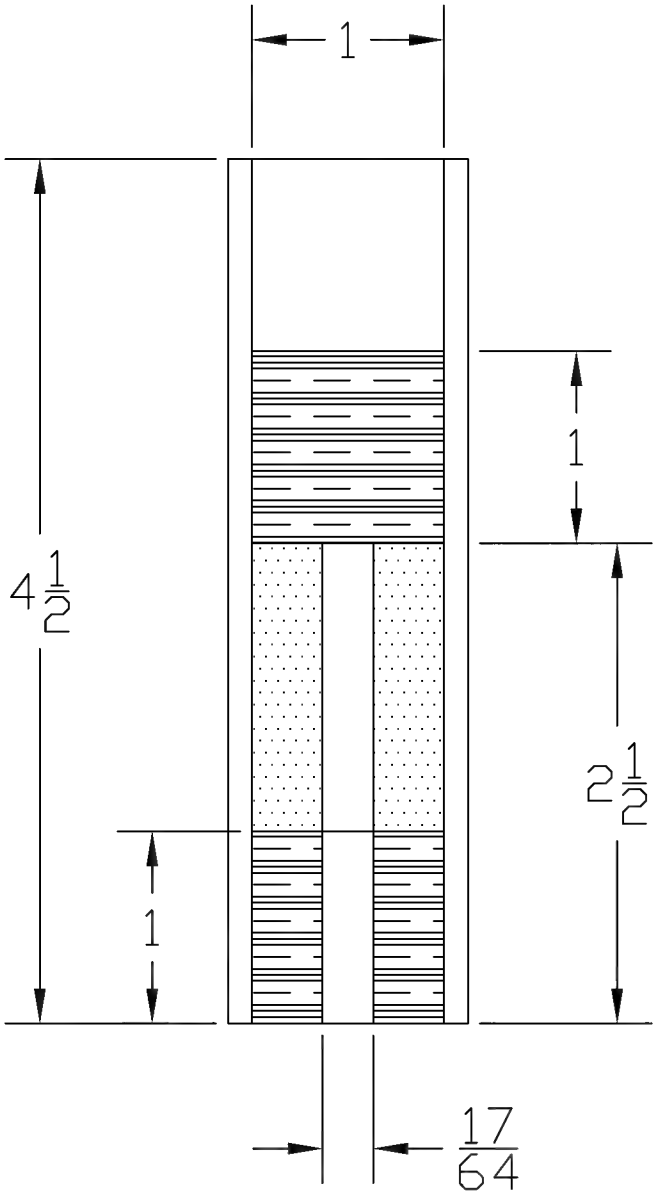


Max Thrust: 57.73 N
Average Thrust: 34.13 N



Max Thrust: 12.98 lbs
Average Thrust: 7.67 lbs

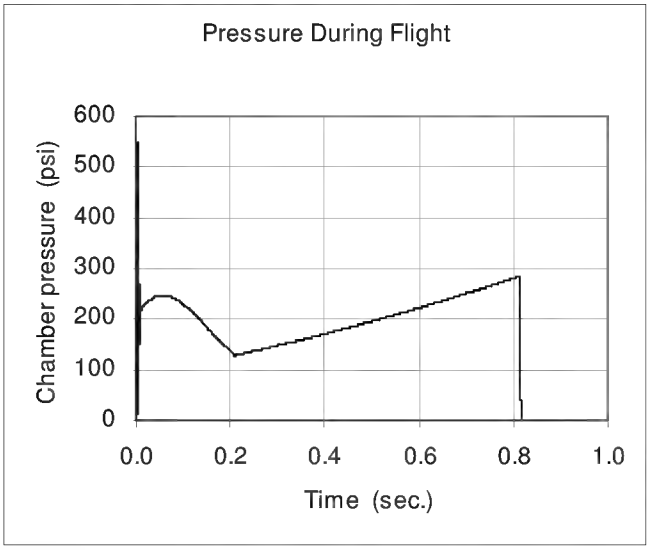
E28 MOTOR DESIGN



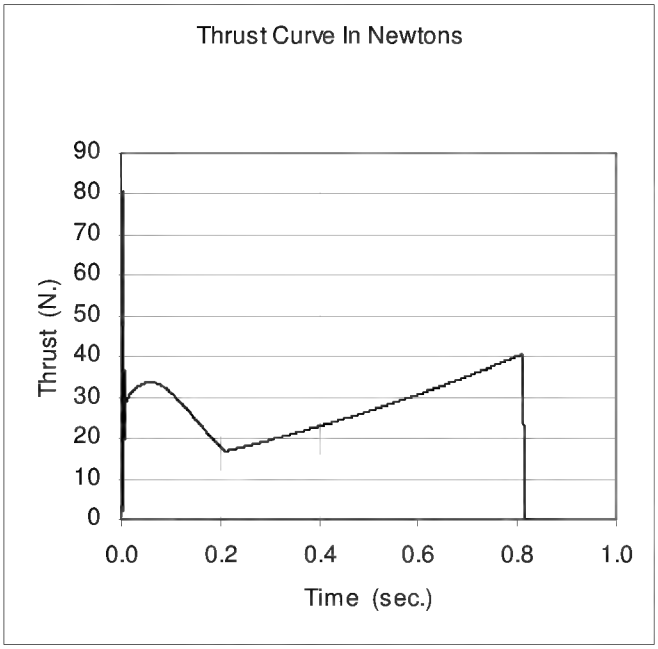
E28 MOTOR DATA

Motor Classification: E
Weight of Propellant: 32.54 g

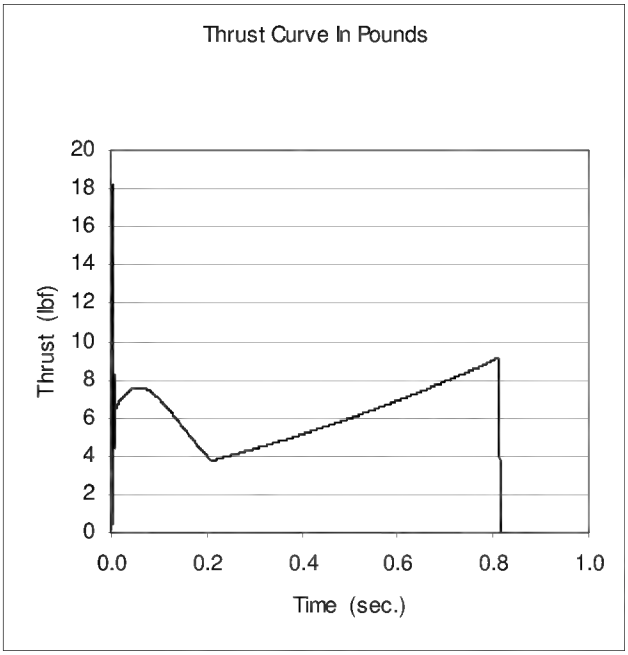
Total Impulse: 22.56 N-sec.
Specific Impulse Delivered: 70.7 sec.



Max Pressure: 575 psi
Time of Burn: .812 sec
Time of Thrust: .817 sec

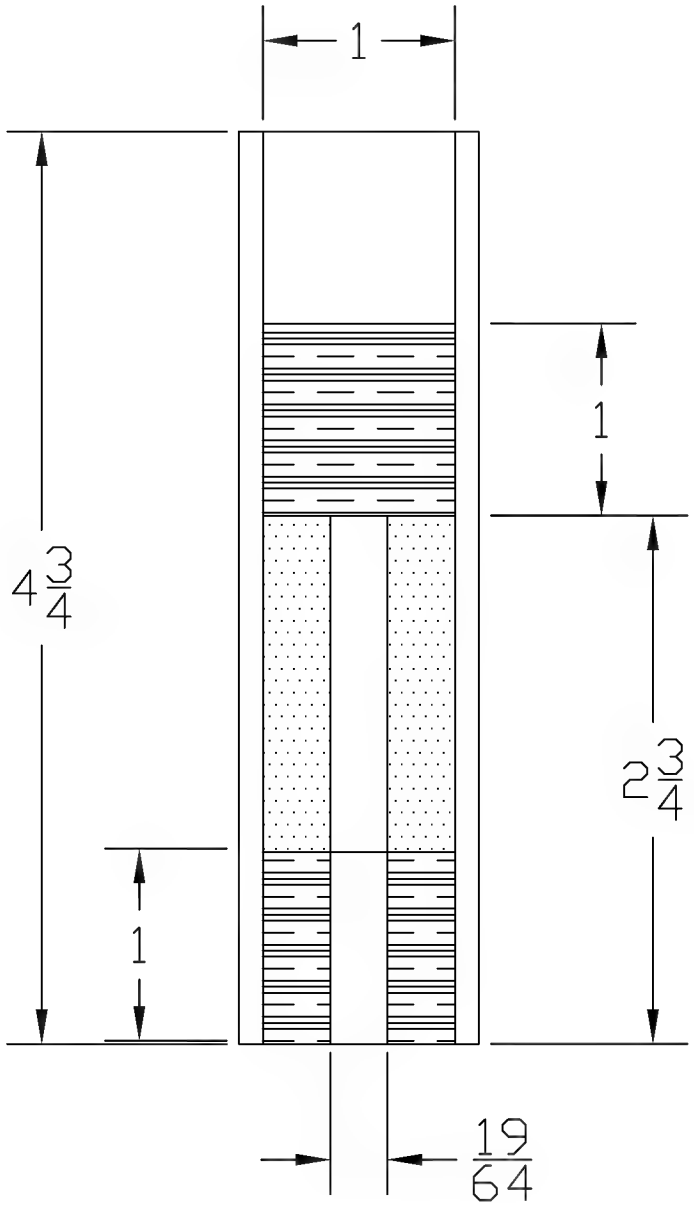


Max Thrust: 82.70 N
Average Thrust: 27.61 N



Max Thrust: 18.59 lbs
Average Thrust: 6.21 lbs

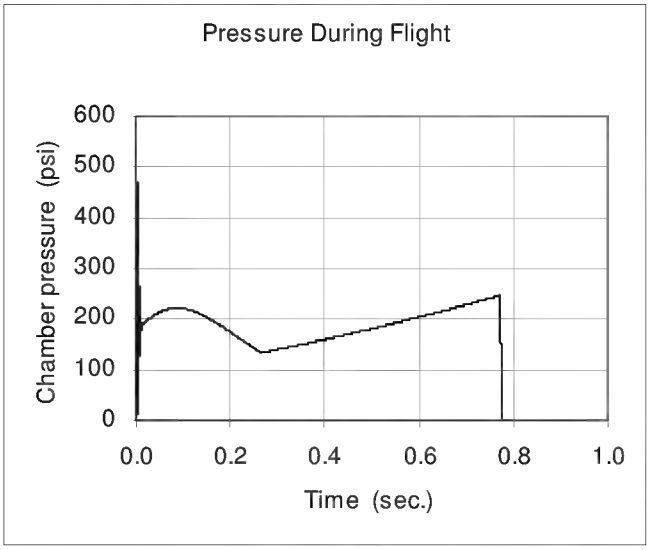
E33 MOTOR DESIGN



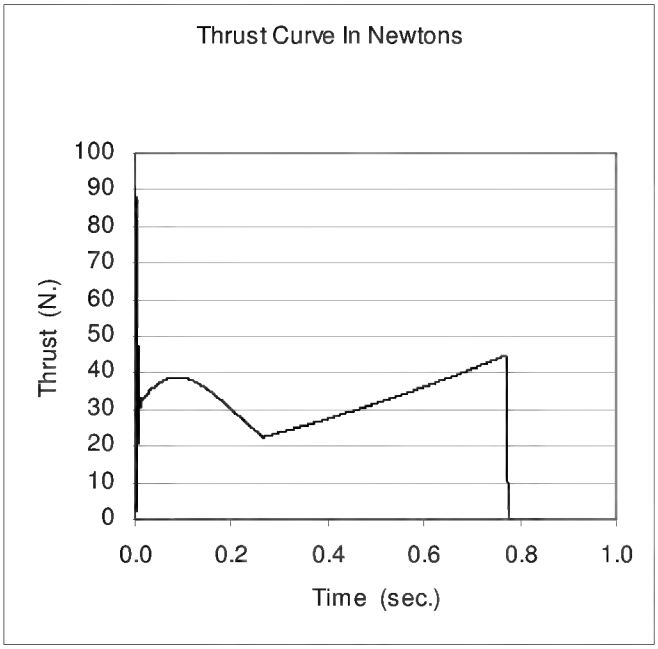
E33 MOTOR DATA

Motor Classification: E
Weight of Propellant: 37.24 g

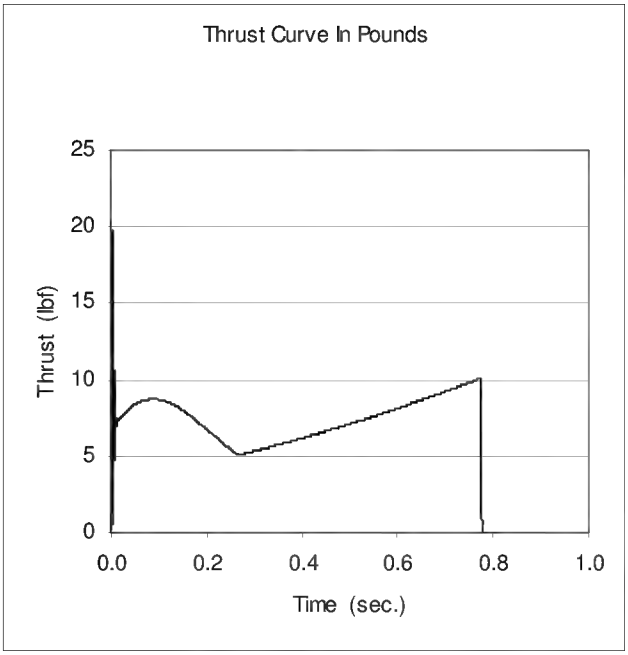
Total Impulse: 25.62 N-sec.
Specific Impulse Delivered: 70.1 sec.



Max Pressure: 495 psi
Time of Burn: .773 sec
Time of Thrust: .777 sec

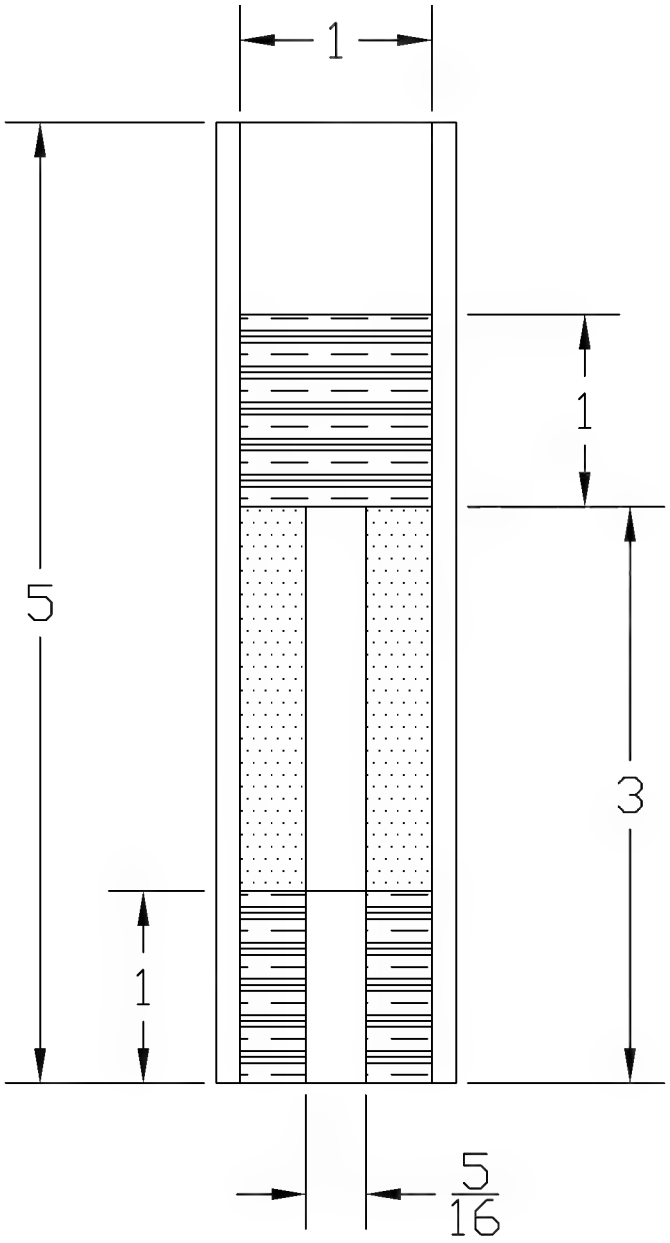


Max Thrust: 90.50 N
Average Thrust: 32.99 N



Max Thrust: 20.34 lbs
Average Thrust: 7.42 lbs

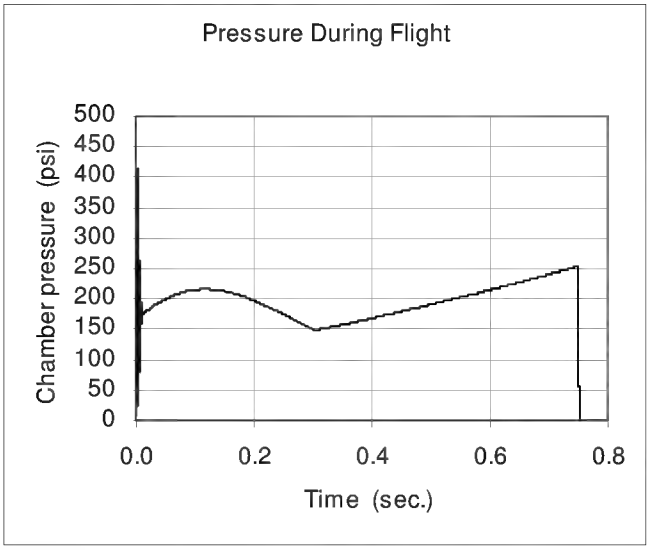
E39 MOTOR DESIGN



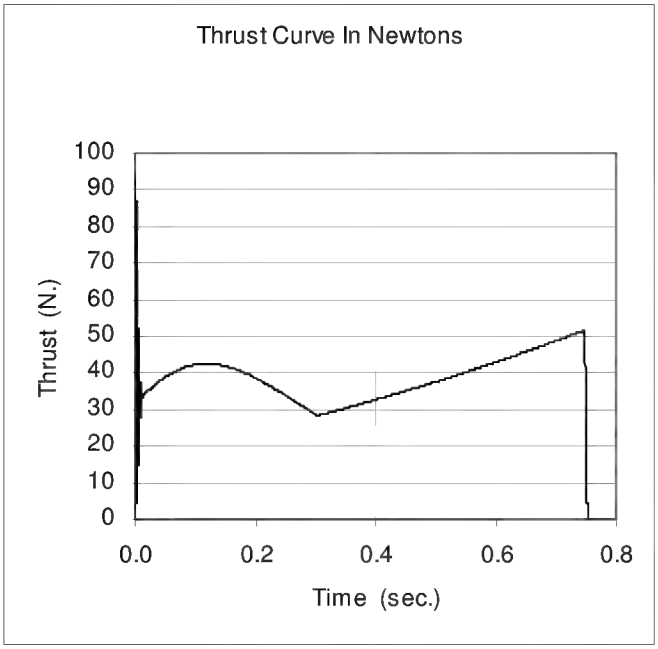
E39 MOTOR DATA

Motor Classification: E
Weight of Propellant: 42.12 g

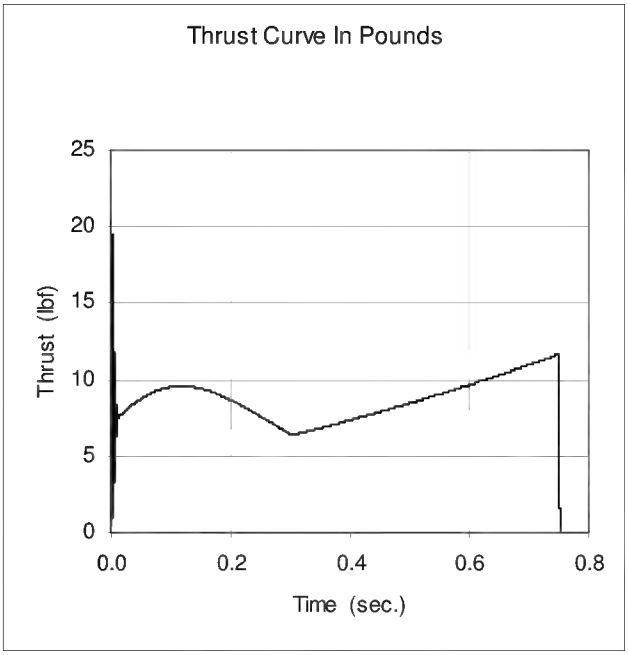
Total Impulse: 29.04 N-sec.
Specific Impulse Delivered: 70.3 sec.



Max Pressure: 461 psi
Time of Burn: .748 sec
Time of Thrust: .753 sec

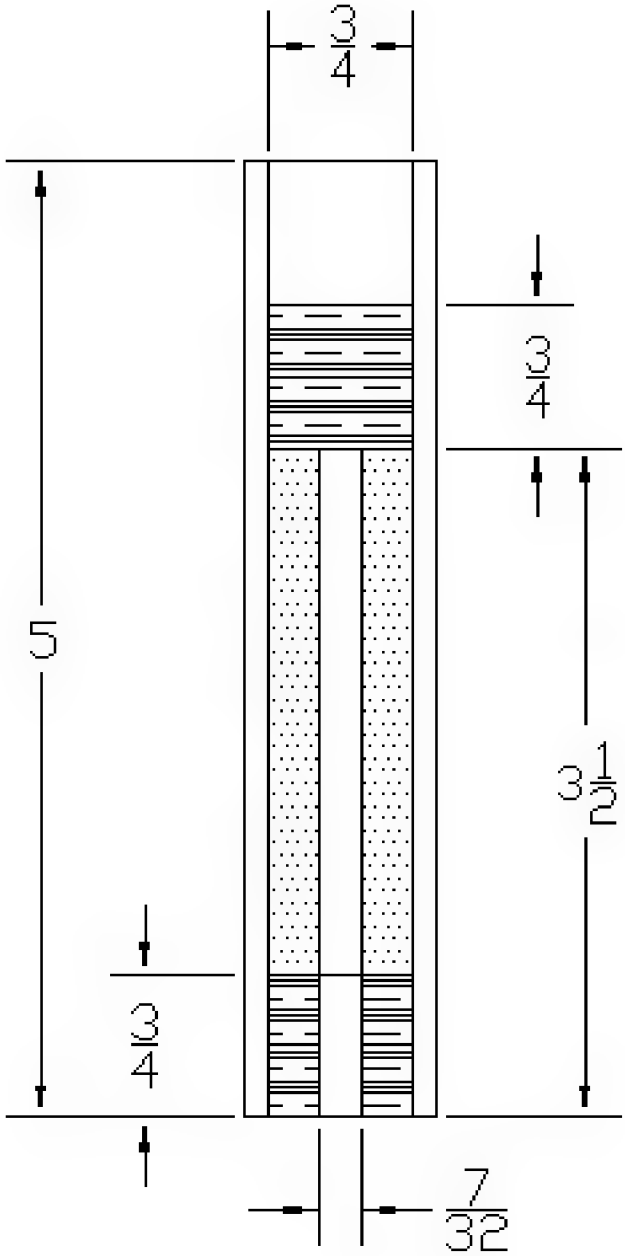


Max Thrust: 93.93 N
Average Thrust: 38.59 N



Max Thrust: 21.12 lbs
Average Thrust: 8.67 lbs

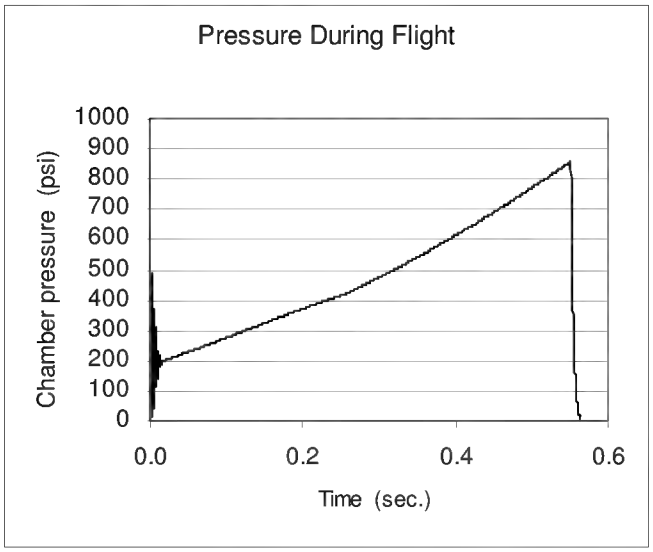
E45 MOTOR DESIGN



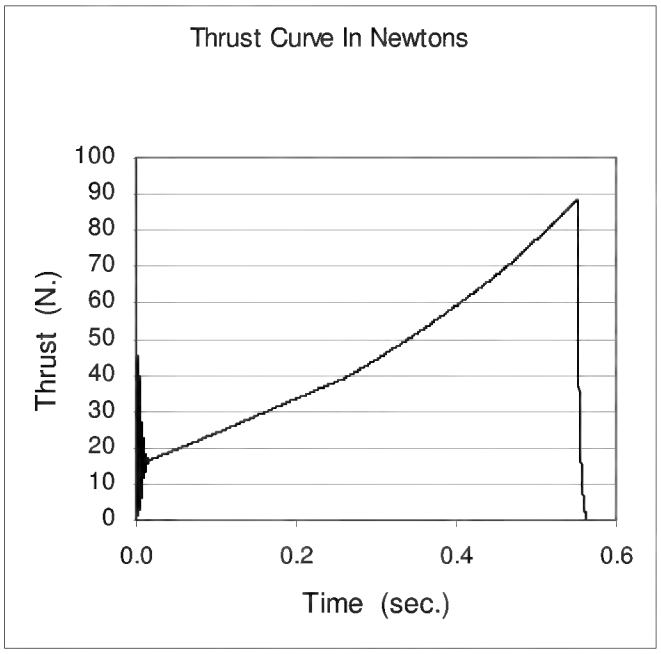
E45 MOTOR DATA

Motor Classification: E
Weight of Propellant: 33.032 g

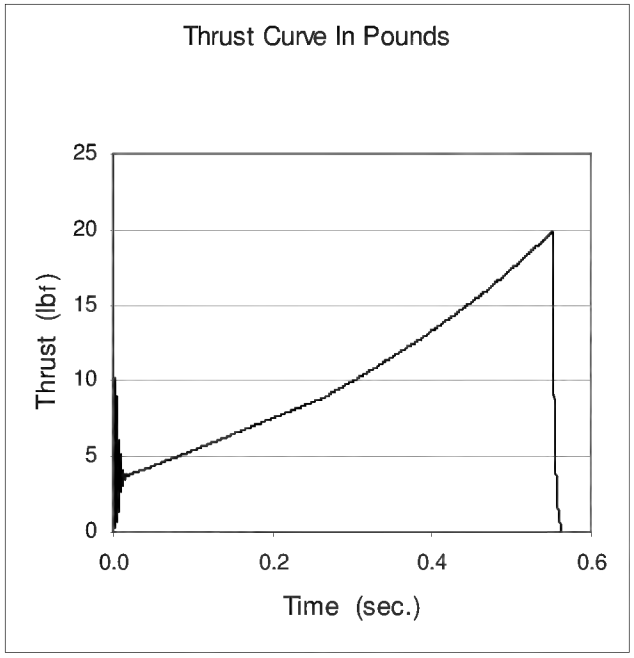
Total Impulse: 25.10 N-sec.
Specific Impulse Delivered: 77.5 sec.



Max Pressure: 873 psi
Time of Burn: .551 sec
Time of Thrust: .563 sec

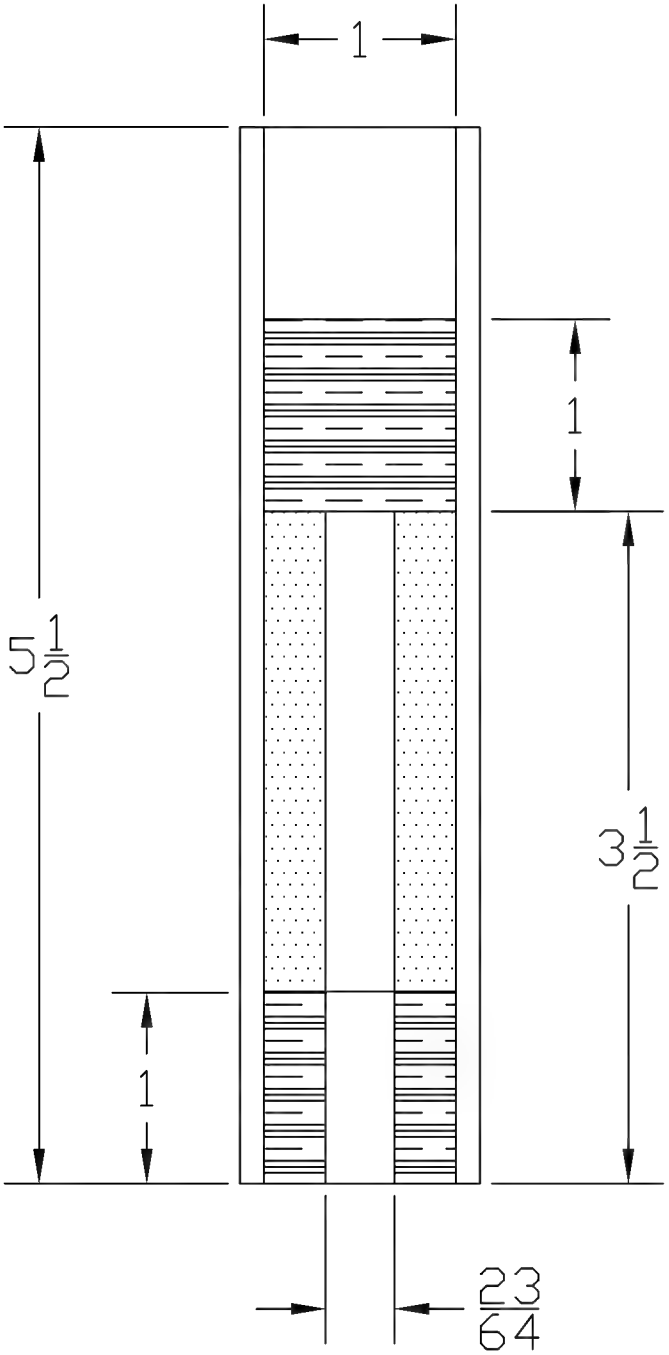


Max Thrust: 88.24 N
Average Thrust: 44.61 N



Max Thrust: 19.84 lbs
Average Thrust: 10.03 lbs

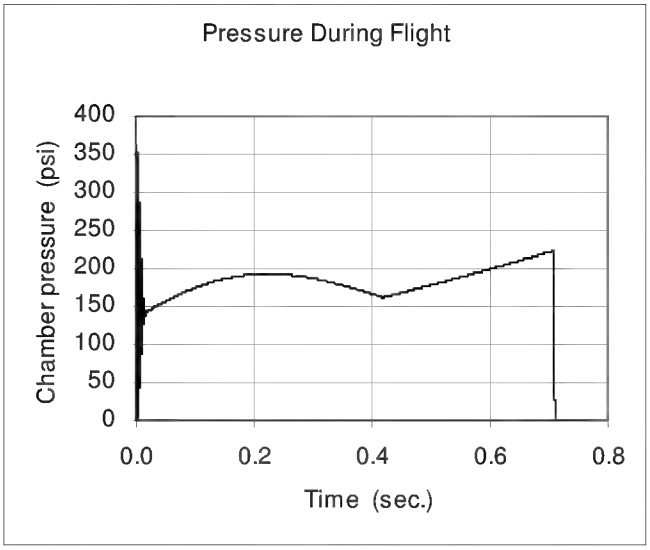
E49 MOTOR DESIGN



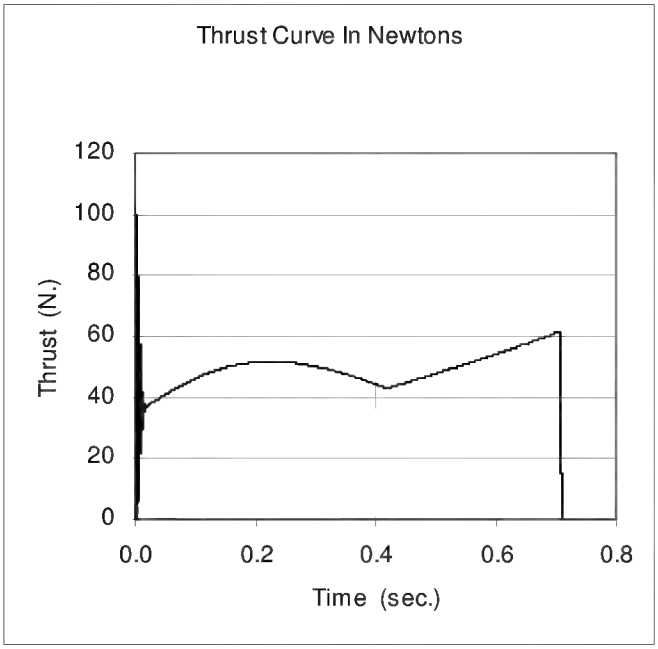
E49 MOTOR DATA

Motor Classification: E
Weight of Propellant: 50.81 g

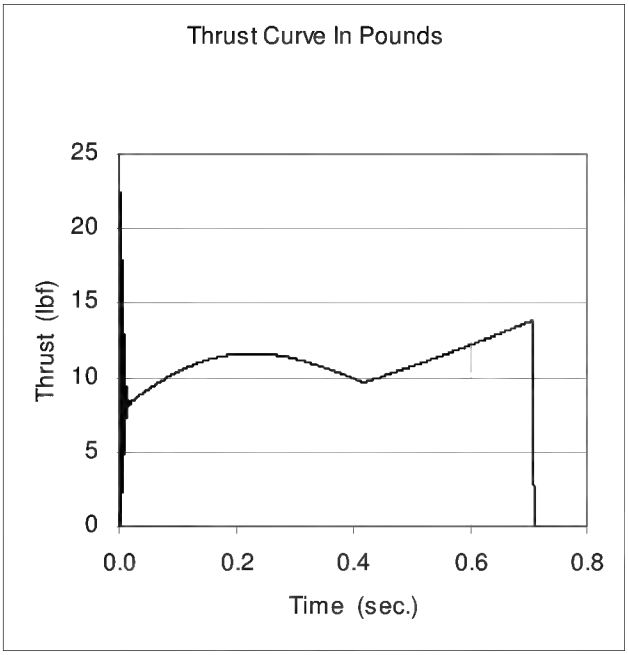
Total Impulse: 34.83 N-sec.
Specific Impulse Delivered: 69.9 sec.



Max Pressure: 377 psi
Time of Burn: .707 sec
Time of Thrust: .711 sec

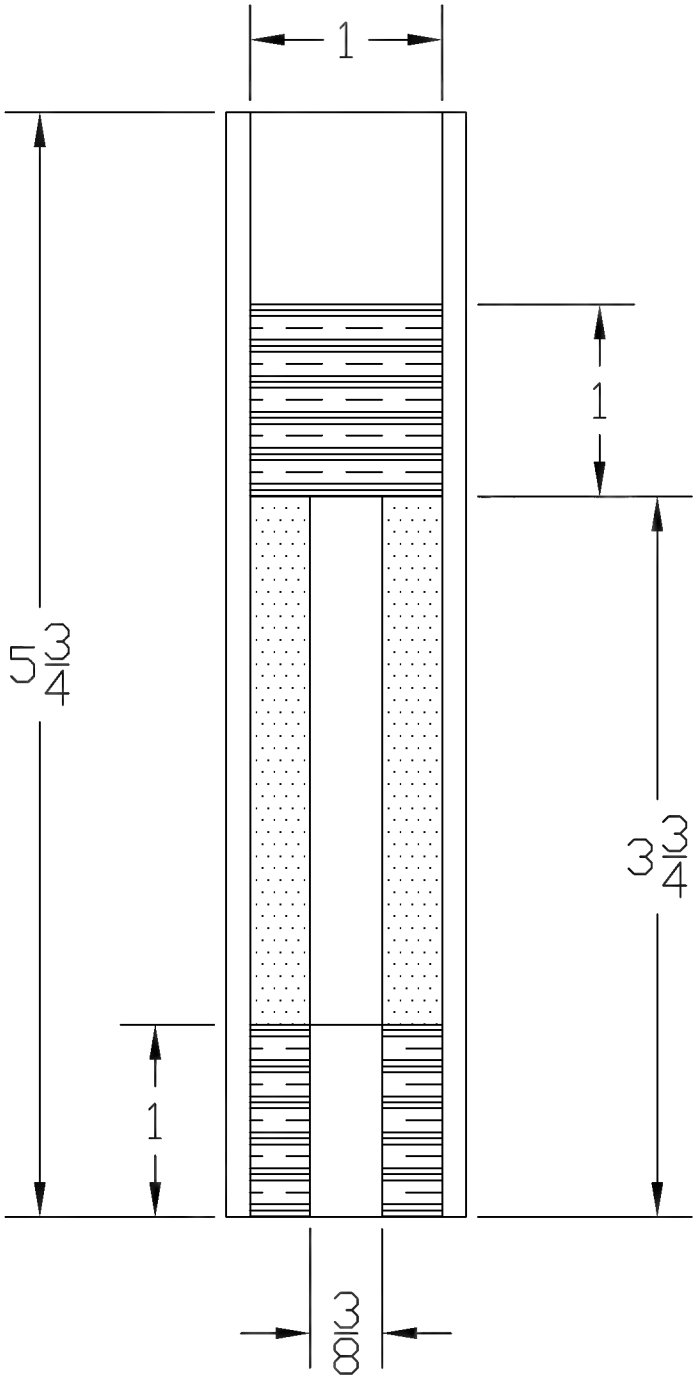


Max Thrust: 102.44 N
Average Thrust: 49.01 N



Max Thrust: 23.03 lbs
Average Thrust: 11.02 lbs

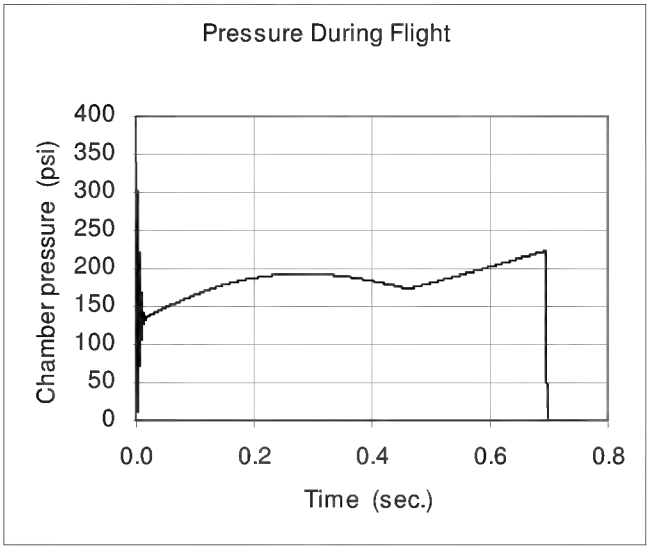
E54 MOTOR DESIGN



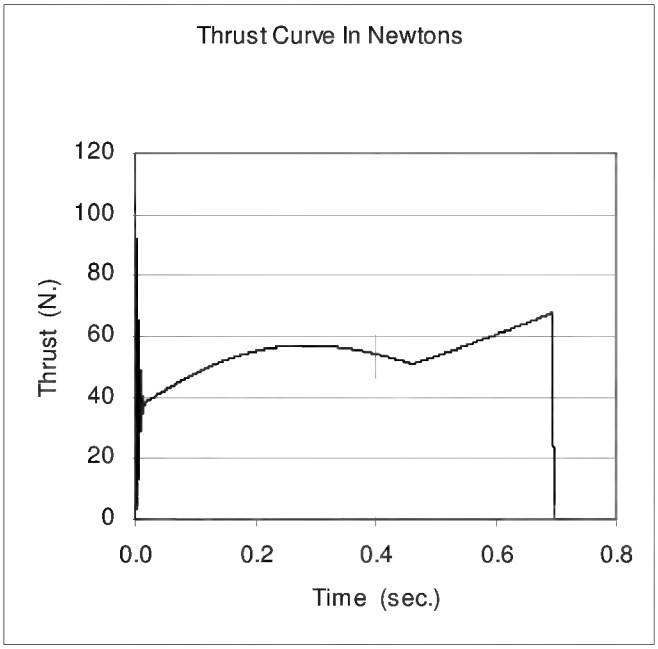
E54 MOTOR DATA

Motor Classification: E
Weight of Propellant: 55.16 g

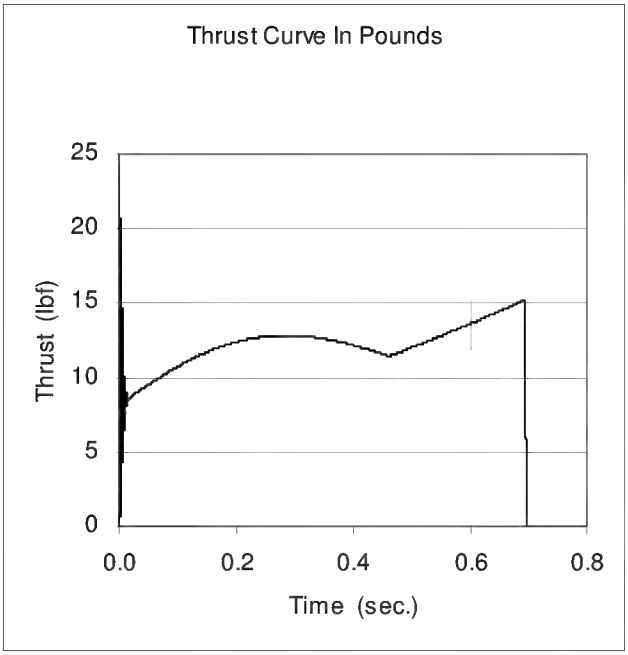
Total Impulse: 37.77 N-sec.
Specific Impulse Delivered: 69.8 sec.



Max Pressure: 354 psi
Time of Burn: .694 sec
Time of Thrust: .698 sec

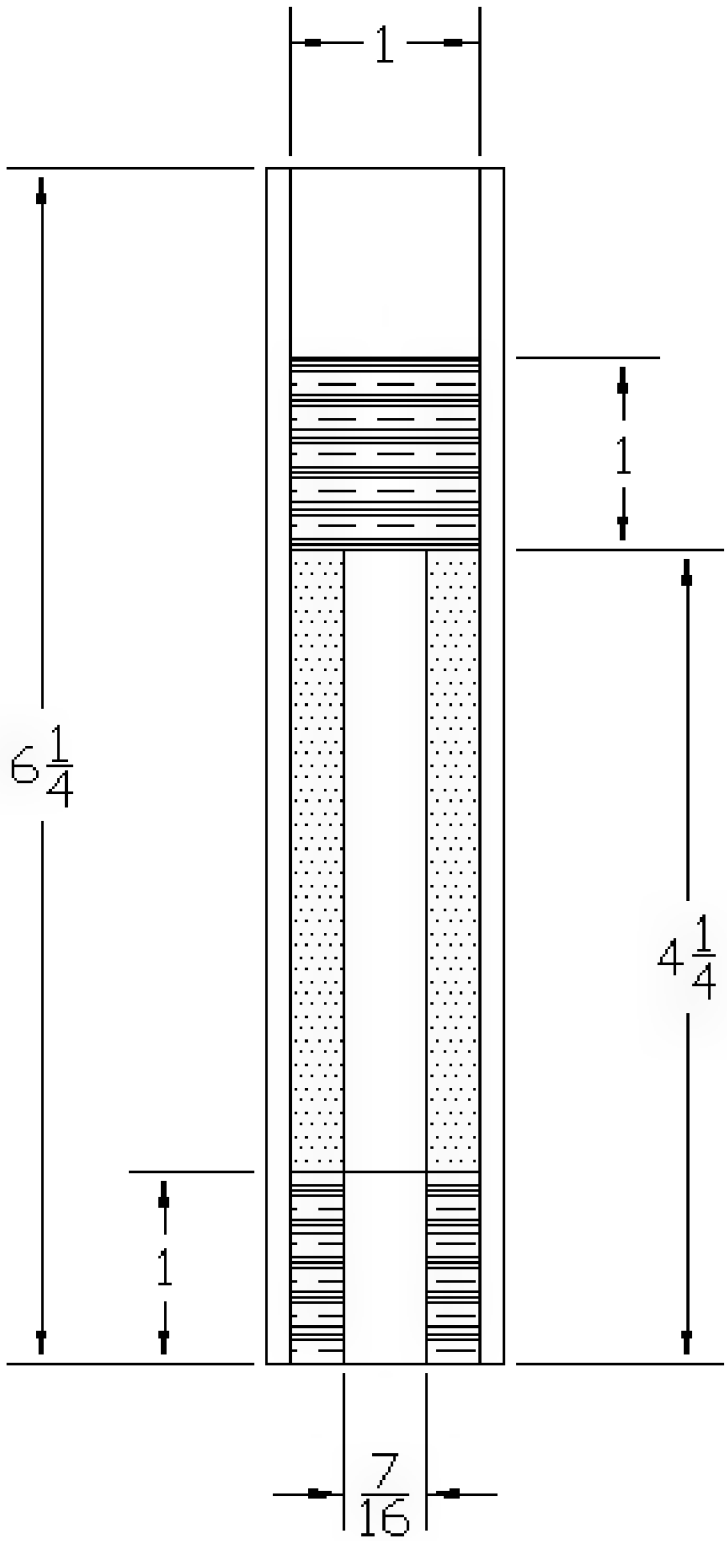


Max Thrust: 104.69 N
Average Thrust: 54.11 N



Max Thrust: 23.53 lbs
Average Thrust: 12.17 lbs

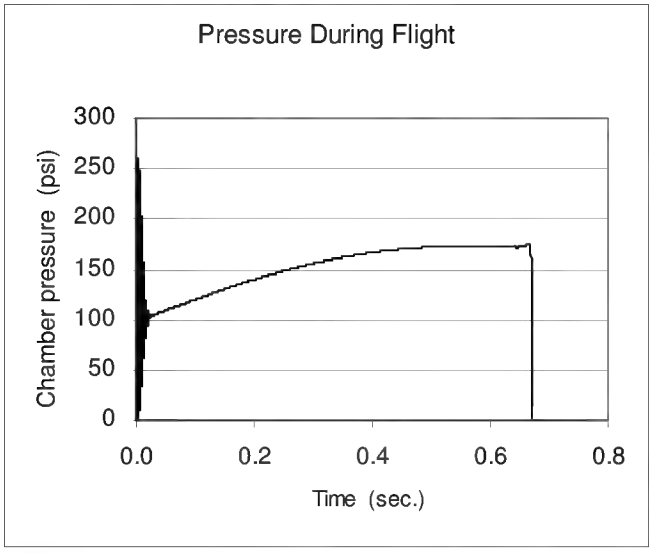
F62 MOTOR DESIGN



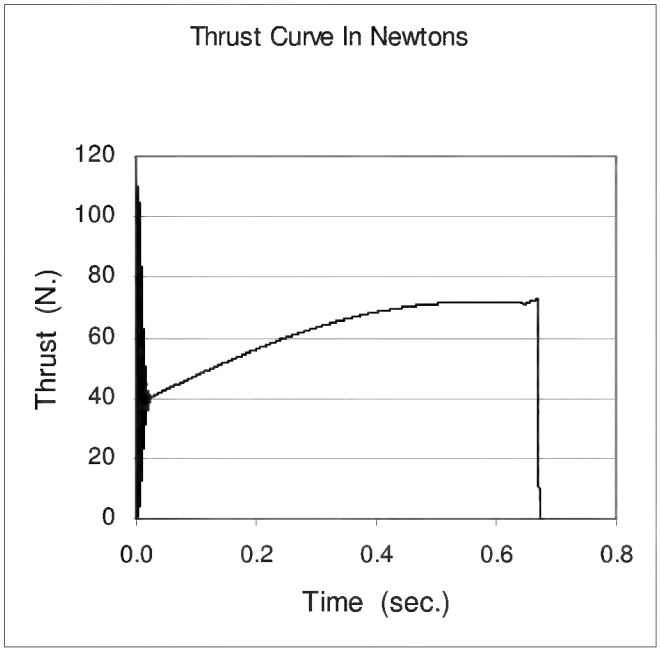
F62 MOTOR DATA

Motor Classification: F
Weight of Propellant: 61.335 g

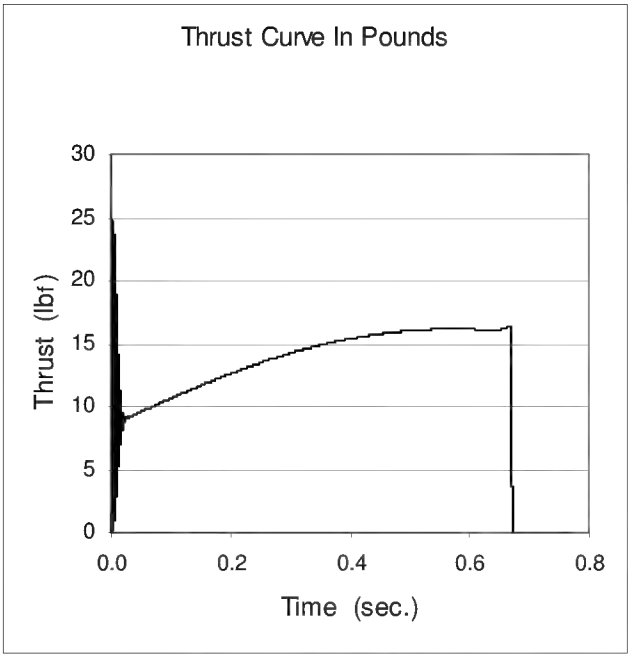
Total Impulse: 41.40 N-sec.
Specific Impulse Delivered: 68.8 sec.



Max Pressure: 276 psi
Time of Burn: .669 sec
Time of Thrust: .672 sec

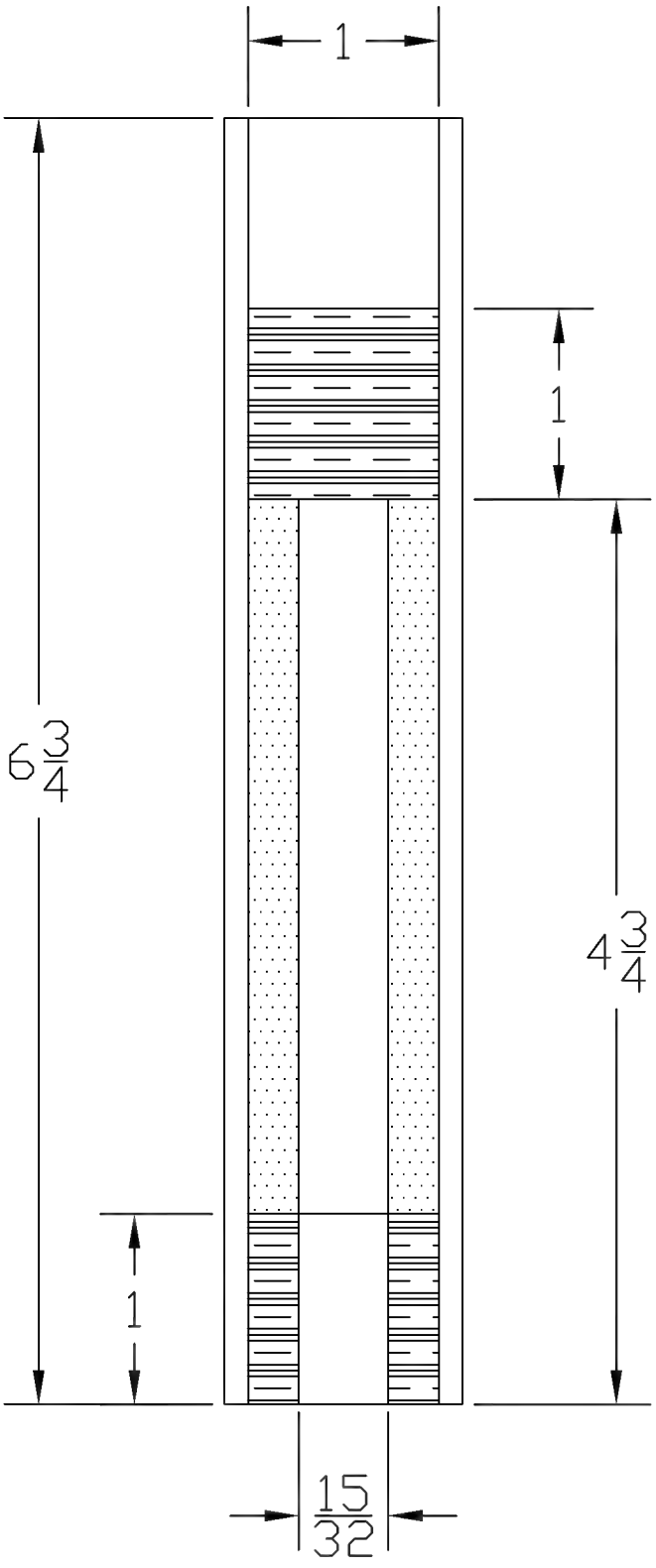


Max Thrust: 110.86 N
Average Thrust: 61.59 N



Max Thrust: 24.92 lbs
Average Thrust: 13.85 lbs

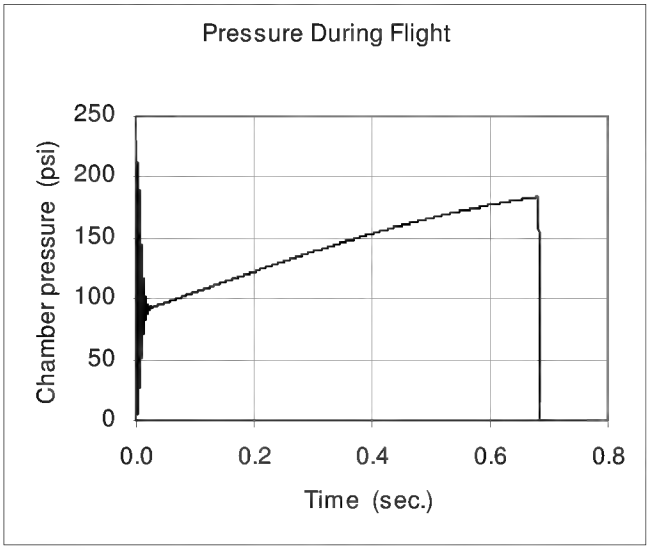
F67 MOTOR DESIGN



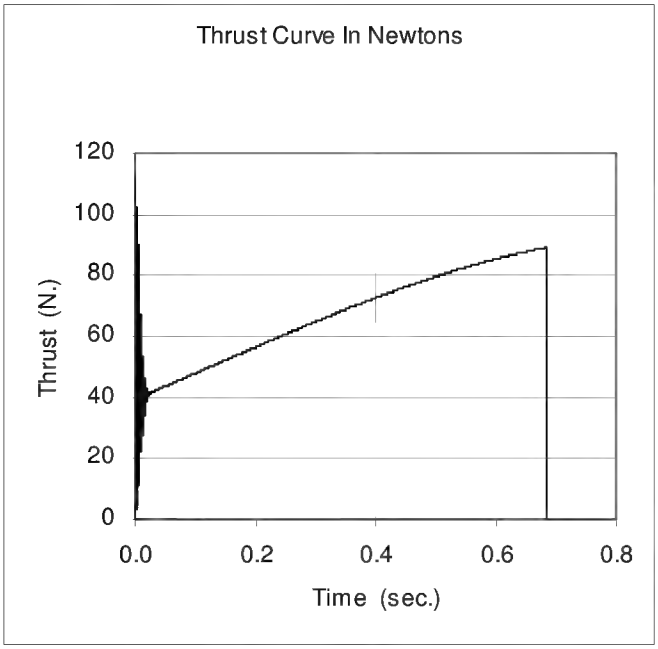
F67 MOTOR DATA

Motor Classification: F
Weight of Propellant: 68.29 g

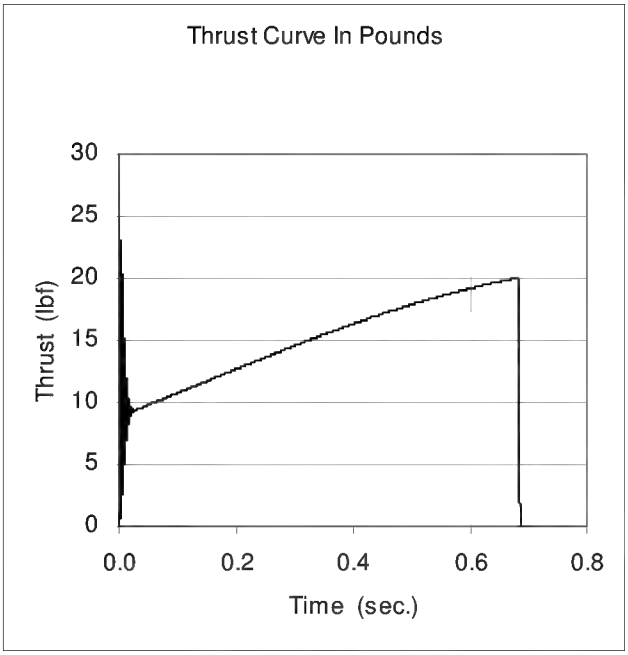
Total Impulse: 45.79 N-sec.
Specific Impulse Delivered: 68.4 sec.



Max Pressure: 245 psi
Time of Burn: .683 sec
Time of Thrust: .686 sec



Max Thrust: 112.31 N
Average Thrust: 66.79 N



Max Thrust: 25.25 lbs
Average Thrust: 15.02 lbs

TIME DELAY MIX

Time delay mix is used as a sort of fuse inside the rocket motor to give a time delay between the thrusting stage of the engine where the propellant is burning and the ejection charge where it will push out a parachute. You could use the propellant itself as a time delay mix but it burns quickly and to get any substantial time delay you would need to pack in a lot of extra propellant on top of the cored section of the motor to get just a few seconds worth of time delay. So we need to somehow slow the burn rate of the propellant down so there is a longer time delay in a shorter length that way we don't have increase the length of the motor tube very much if at all.

To slow the propellant burn rate down we are going to add a percentage of baking soda. Baking soda is sodium bicarbonate and it will inhibit the burn of the propellant therefore slowing it down. It acts as a burn rate modifier so the higher the percentage of baking soda the slower the propellant will burn. Baking soda can be purchased at the grocery store in the cooking isle.

Figure 10-1: Baking soda.

To mix your time delay mix you are going to need some prepared rocket propellant from this book and baking soda. Just add in 15% baking soda to the propellant and shake it up well in a plastic container just like you did to prepare the propellant. So if you have 100 grams of propellant you must add in 15 grams of baking soda for a total of 115 grams of delay mix. You can change the amounts in proportion to fit the total amount of delay mix you need.

After you mix it up it is ready to load or store. To store this delay mix just place it into a "zip lock" bag and put it in the homemade desiccator just as you do with the propellant in the "SOTRAGE" chapter. Also make sure you label your bag well so you don't mix it up with the propellant since they look the same.

This delay mix burns at about 1/16 inch per second but you can test it yourself by packing some in a tube of a known length and timing the burn and then take the number of inches in length it burned and divide it by the time it took to burn that distance.

PARACHUTE EJECTION

To keep your model rockets from falling back to earth at high speeds and damaging the model or causing damage to its surroundings you must have a parachute eject when it reaches its maximum height. The parachute slows the rocket down and floats it gently back to earth. But to pop a parachute you must modify your rocket engines to do so. There has to be a force that pushes upwards to push the parachute out of the rocket body and there also must be a time delay from when the rocket engine is thrusting to when the parachute should deploy. Black powder is used to create the upward force at the end of the thrust stage and a delay mix discussed the chapter "DELAY MIX" is used to create the delay time to when the parachute will eject.

To make a parachute ejecting rocket engine you must modify it some. Construct the engine as you regularly would and ram the nozzle into the PVC pipe and ram in the propellant after that now comes the changing part. Instead of ramming in a clay cap on top of the propellant you are going to need to ram in some delay mix on top of the propellant. The amount of delay mix is dependant on how much time delay you want from the firing of the engine until the parachute pops. Since the delay mix presented in this book burns at 1/16 of an inch per second you can calculate the thickness of the delay grain by multiplying 1/16 by the number of second's delay you would like. Below is a table of delay times and their corresponding thickness of delay mix.

Time Delay (seconds)	Inches of Delay Mix
1	1/16
2	1/8
3	3/16
4	1/4
5	5/16
6	3/8
7	7/16
8	1/2
9	9/16
10	5/8

For example I would like a 4 second delay in my B11 engine so I would ram in ¼ inches worth of delay mix.

Now you can ram in the clay cap just as you did for the normal construction of the engines on top of the delay mix. After you ram in the clay cap you are going to need to drill a 1/16-inch hole through the top clay cap down to the delay mix. This hole allows for the flame to pass through the clay cap to ignite the ejection charge. I use my fingers to twist the drill bit in to the clay so I don't over shoot and drill down into the delay mix. I stop when I stop seeing clay on the drill bit and I start to see a little delay mix on the drill bit. This tells me that I have drilled all the way through the clay. You could also mark the drill bit with a piece of tape to measure the depth of the clay so you don't drill past the tape marker on the bit.

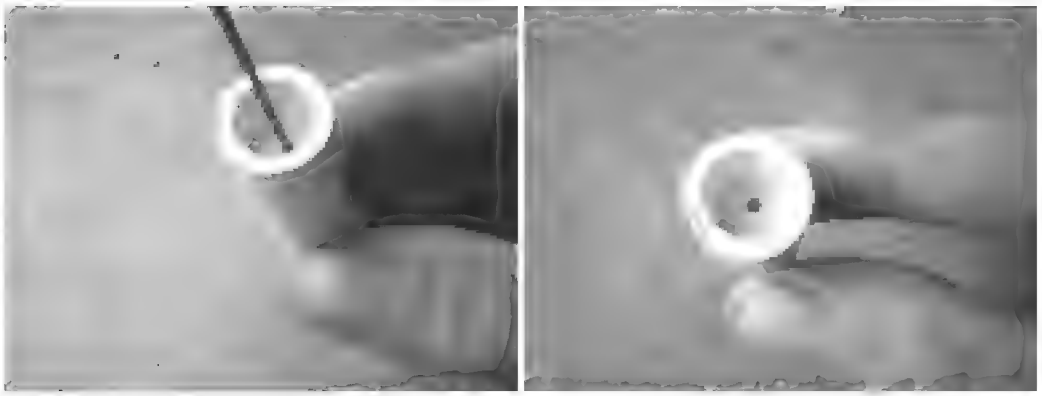


Figure 11-1: Drilling a 1/16-inch hole in the top clay cap down to the delay mix.

Now fill the small hole with some black powder and pour enough black powder in the top to just cover the clay. It should only be a few grains thick. It does not take much black powder to pop a parachute. If you add too much you could damage your parachute or rocket and if you add too little the parachute will not deploy.

Figure 11-2: Cover the clay cap with just a little black powder.

Now cut a square just a little bigger than the diameter of the rocket engine out of an index card or some card stock or other thick paper. Now just press this piece of paper into the engine to make a cap to hold the black powder in place.

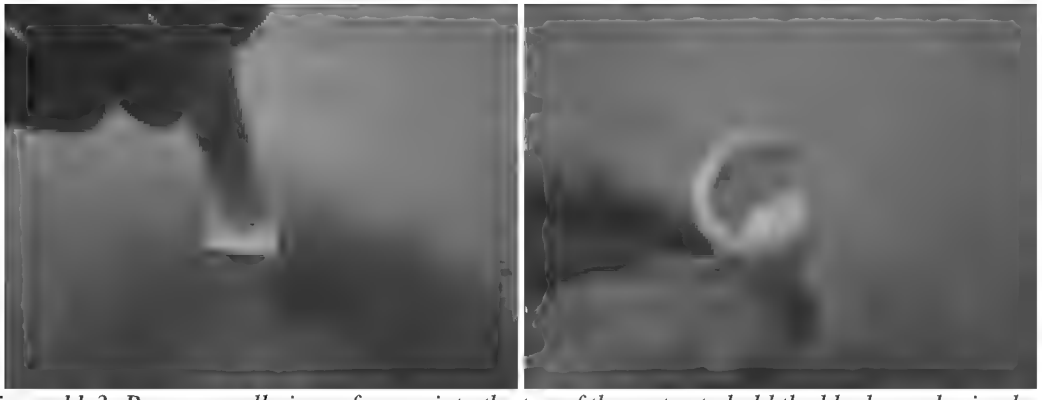


Figure 11-3: Press a small piece of paper into the top of the motor to hold the black powder in place.

Now you are done! You now have an engine that is capable of popping a parachute out of a model just like the manufactured commercial rockets.

How it works is when the engine is done burning its propellant the delay mix is burning acting like a timer and once it reaches the small hole at the top it will ignite the black powder in the hole and then igniting the black powder at the top on the clay and then causing a gas expansion and generating pressure upward pushing out the paper cap and eventually the parachute above it in the rocket body.

NOTE: You may also have to account for the extra room needed in the motor body tube to fit in the delay mix and ejection charge by making the motor tube longer than the original design without the ejection charge.

Below is an example cross section of a B11 motor with a 4 second time delay and parachute ejection. Notice how the motor tube is slightly longer than the design without the parachute ejection. Although this may not be necessary for all the designs some of them it will be depending on how much time delay you are going to use.

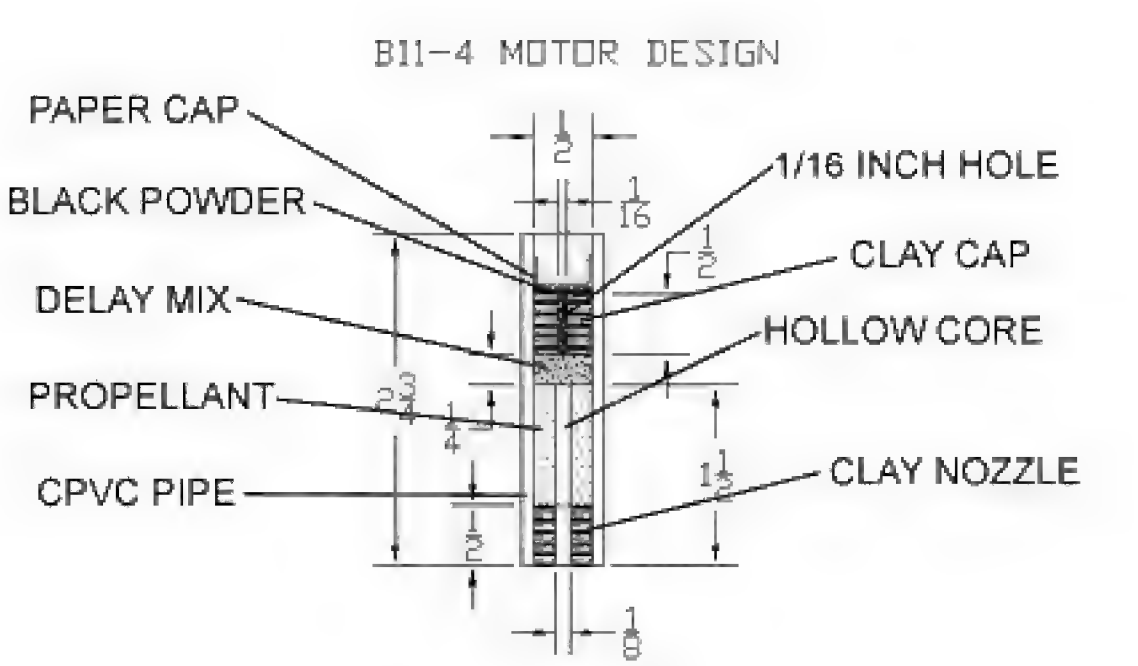


Figure 11-4: A cutaway view of a parachute ejecting motor with a 4 second delay.

PREPARING THE ENGINES TO FIRE

To be able to use these PVC engines in a model rocket you have to make a few modifications to them to make them fit correctly into the rocket. To keep the engine from pressing up into the body tube of the rocket you must make a "thrust ring". This is done by simply wrapping a layer of masking tape around the bottom of the engine until it is thick enough that the motor will not insert into the rocket past the tape ring. This also keeps the end of the motor away from the rocket body and thus keeping the hot gases at a distance from the rocket preventing damage to the rocket.

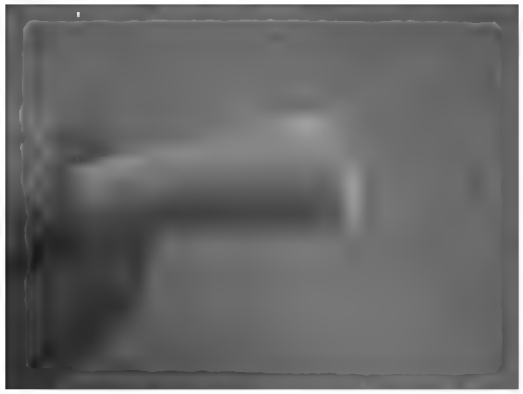


Figure 12-1: Masking tape "thrust ring".

Also if the rocket engine doesn't fit very snugly into the model rocket you may have to build up the outside of the engine with some masking tape so it increases the diameter of the engine and makes it fit more tightly into the rocket. The motor must fit tightly into the rocket or the parachute ejection charge may blow the motor out of the rocket and not push out the parachute.

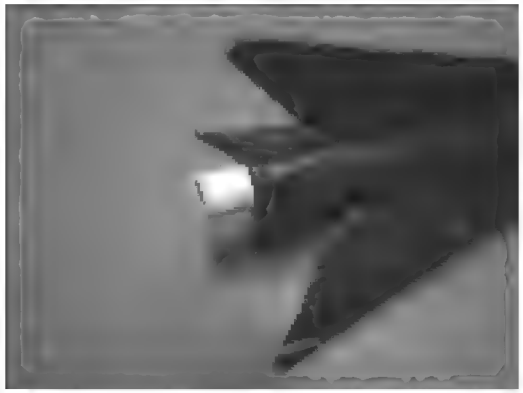


Figure 12-2: Motor inserted into model rocket with thrust ring sticking out.

Now the engine just needs an electric igniter inserted into it to be able to remotely fire it. For the larger engines with a large core and nozzle diameter you can just simply insert the igniter into the nozzle and up into the core of the engine so it is touching the propellant inside the engine and securing it with a piece of tape on the outside. Just tape the wire to the nozzle with a small piece of masking tape.

For the smaller engines that have a nozzle and core diameter too small to fit an igniter inside it you are going to have to modify the engine a little bit. First pour some black powder into the nozzle and core of the engine and fill it the whole way.

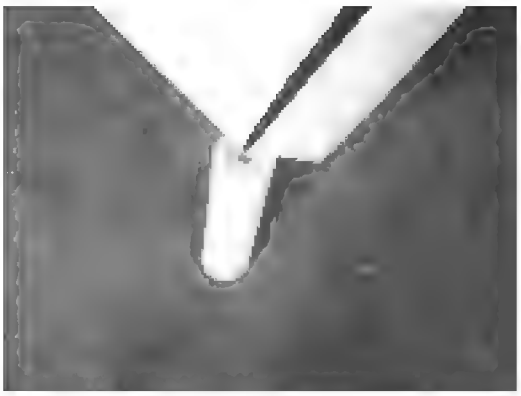


Figure 12-3: Filling the core with black powder.

After you fill the core continue to pour a little black powder around on the top of the nozzle on the outside.

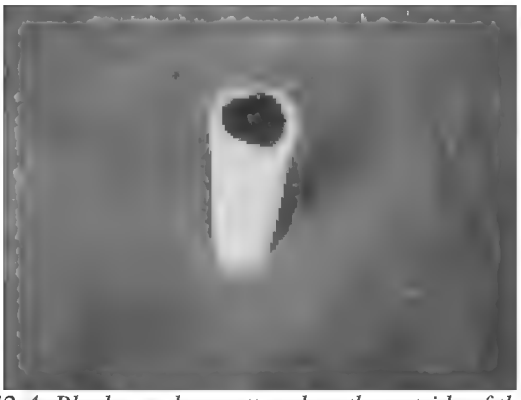


Figure 12-4: Black powder scattered on the outside of the nozzle.

Now just fold a piece of tape over the nozzle end and black powder to hold it all in place.

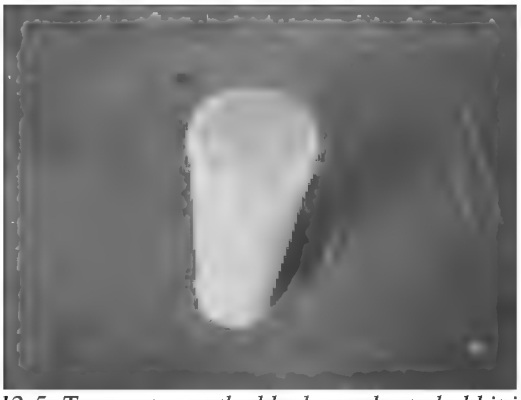


Figure 12-5: Tape put over the black powder to hold it in place.

Now you can just tape an electric igniter to the tape with the black powder in it. When the igniter fires it will ignite the black powder in the tape and shoot the flame into the core of the motor with the black powder that is there and it will all ignite the propellant at once.

ELECTRIC IGNITERS

An electric igniter or electric match is exactly what it sounds like, a match that can be ignited remotely by electricity. This is the safest way of firing pyrotechnic devices and rockets. This way of firing gives you a large distance and guarantees you are far away when the device or rocket fires.

This electric igniter is used with the electrical firing system discussed elsewhere in this book.

First get a pack of paper matches or book matches. DO NOT use wood matches or strike on anything matches because they could ignite when you attempt to insert it into the rocket engine from the friction.

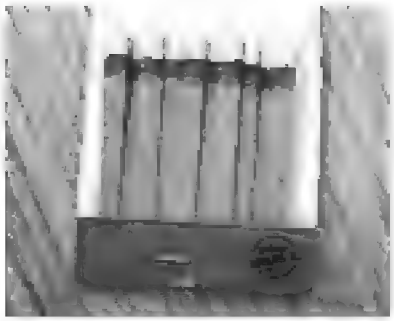


Figure 13-1: A pack of paper matches.

Cut a slit on the match head with a razor knife.

Now get two small pieces of copper wire about 2 inches (strip the insulation if it has any) and a small single strand of steel wool. Steel wool can be found at hardware stores or Wal-Mart. You just need a single wire from this steel wool and it should look like a hair, it is very thin. The thin steel wool provides a lot of resistance to the electrical flow therefore making it glow red-hot when current is applied to the circuit.

Note: If you require a longer length igniter for reaching into the longer cores of bigger engines then just use a length of copper wire with the insulation still on it but just strip about ½ inch of it off on both ends to construct the rest of the igniter.

Now wrap the strand of steel wool around one of the copper wire pieces and take the other end of the steel wool and wrap it around the other copper wire so it forms a bridge with copper wire bridged with steel wool then the other copper wire on the other side.

Now put this bridge of wire over the match head you had form earlier. The steel wool should go through the slit you made in the head and the copper wires should be on either side of the paper match.

Take a piece of masking tape and wrap it around the stick of the match to secure the two copper wires to the match and bend the copper wires out away from the match. Your electric igniter is finished! Just hook the wires from the electrical firing system to the copper wires on the electric igniter to complete the circuit and fire your rocket. When an electrical charge is passed through the igniter the match should ignite.

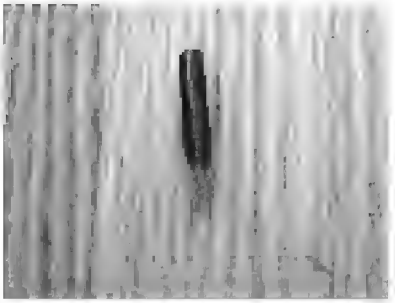


Figure 13-2: A Finished electric igniter.

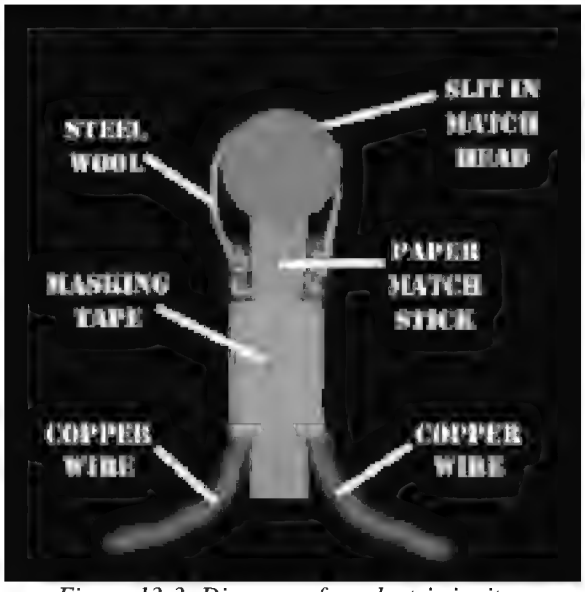


Figure 13-3: Diagram of an electric igniter.

ELECTRICAL IGNITION SYSTEM

The electrical ignition system is used to fire devices electronically at a safe distance and at a specified time. This system is designed to ignite the electric igniters discussed in a different section of this book. To make a firing system you're going to need a strong battery. A 9-volt battery will work but I myself have a larger 12-volt battery to provide more power. Now you are going to need a large length of copper wire. Copper wire works best because it is the best conducting wire. I have a few hundred feet of copper wire on a spindle. Now you need a button and some alligator clips. Get a tube that will house your button well, this will be your firing switch for holding in your hand. Solder a piece of copper wire to the one of the button terminals. Now solder one of the wires from the spindle of long wire to the other button terminal. Glue the button in place in the tube on the top of it. Now solder an alligator clip to the small wire from the button and another clip to the other wire from the spindle. These clips are used to hook up the battery. You can also use clips on the other end of the wires for connecting the electric igniter or you can just wrap the wire around the igniter and tape it in place to hold it.

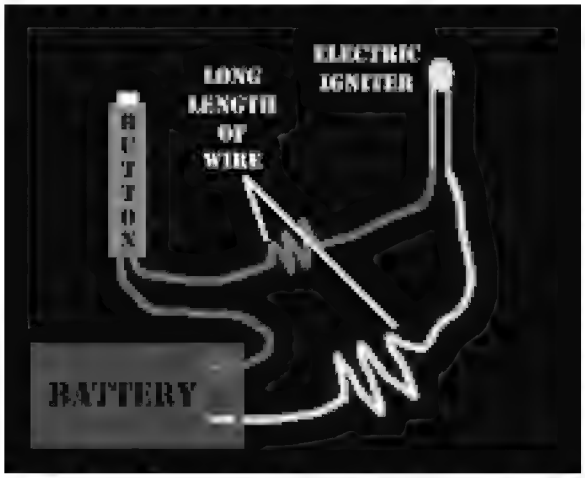


Figure 14-1: Diagram of an electrical ignition system.

When using this to fire roll out all your wire from the launch location to the bunker where you are. Now hook up the electric igniter to the wires at the one end and prepare the device for firing. Now go to your bunker and hook up the battery with the clips. The device is now ready to be fired and no one should approach the launch area. Now all you do is have to push the button to fire the device!

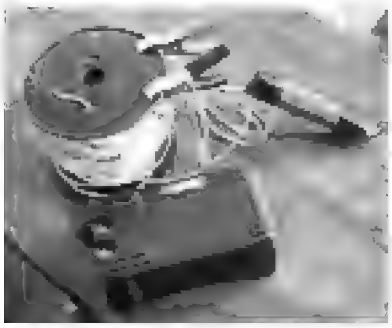


Figure 14-2: An electrical ignition system.

STICK ROCKETS

The simplest way to test fly one of your rocket engines is on a stick. A simple stick attached to the side of the motor can provide the necessary balance it needs during flight. These are extremely easy to construct.

First check your local laws about flying stick rockets because they may be considered fireworks and some states prohibit such fireworks. Also be careful flying these stick rockets in dry areas because since they just fall back down to earth with no recovery system they can cause fires or damage to the area they land in.

There are many sources of sticks. You can buy wooden dowel rods for the large rocket engines or I sometimes use golden rod sticks. Golden rod is a plant that grows here in the northern part of America. I also like to use wooden barbeque sticks for grilling on the small rocket engines. Just look around and I'm sure you can find a source for cheap or even free sticks.

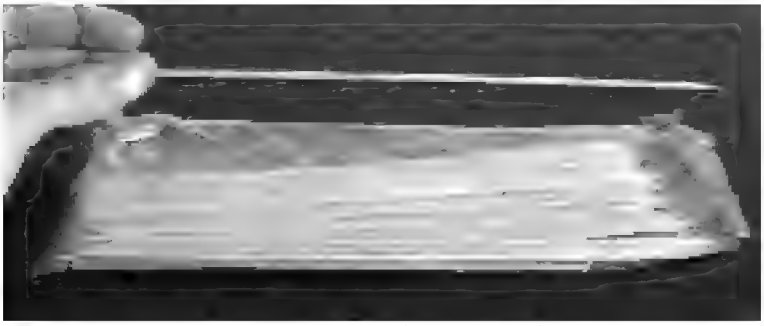


Figure 15-1: Wooden BBQ sticks.

To attach the stick I usually just tape it on the side of the rocket engine. You could also use glue if you wish but I find tape to be faster and easier.

Now you need to make sure your rocket is balanced. Put a rod or your finger just behind the nozzle of the rocket engine and if it tilts forward the engine is too heavy and it needs a longer stick. If the rocket tilts backward toward the stick then the stick is too heavy and you need a shorter stick. If it balances even on the rod then the stick is the correct length.

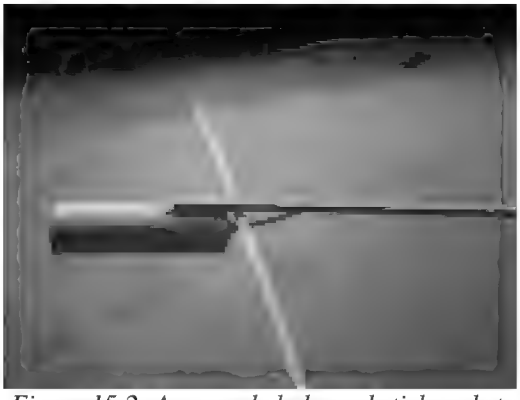


Figure 15-2: A properly balanced stick rocket.

To fly these just put the stick portion in a pipe buried in the ground vertically or for the smaller engines that are so called "bottle rockets" since they can be fired out of the neck of a soda bottle. I sometimes like to use bricks with holes in then and stack them up on each other to insert the stick into and fire them that way. I also use the bottom half of a floor fan stand witch contains a metal pipe attached to an "X" shape stand that holds it upright and I just insert the stick into the vertical metal pipe.

MAKING YOUR OWN MODEL ROCKET

You can easily construct your own model rocket to fly on the rocket motors presented in this book from scrap, materials around the house and they function and look just as good as the commercial kits. You just have to use your imagination on constructing these and you can make just about any model design you want for very cheap if not free. In this chapter I will walk you through the construction of a model rocket just to give you some ideas on the types of materials to use and the general design of a model. You don't have to copy directly when making your own model so try and be creative and find new ways to build models and new materials and designs methods to use. Just remember the rocket has to be light enough for the engine to lift it so choose your materials and sizes wisely.

I am going to construct a rather large rocket to fly on the F class engines in this book. The F class engine is 1 inch in internal diameter and about 1-1/4 inch in external diameter. So I have to design the rocket body to to fit this size engine. I found a thick cardboard tube that is a little larger than the motor and it is about 2 inches in diameter. Now for your rocket you can use other cardboard tubes such as the ones in wrapping paper or the ones in paper towel rolls just look around and be creative. You can also make your own cardboard tube by rolling cardstock or poster board around a dowel and taping or gluing it in place and then removing it from the dowel and then you are left with a tube.

Now you want to cut a small section off the cardboard tube for a nose cone assembly. My section is about 3 inches long. The rest of the tube is for the body tube of the rocket.

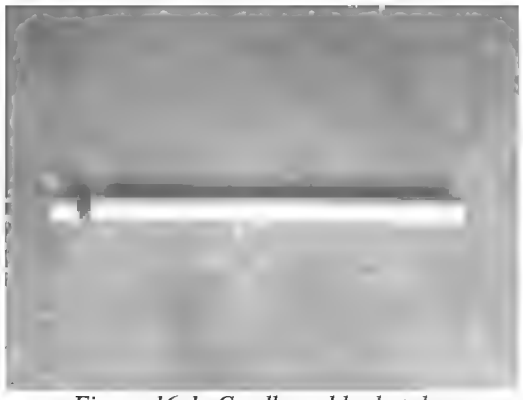


Figure 16-1: Cardboard body tube.

Now you need to make a motor mount so the rocket motor fits snugly into the center of the body tube in the rear. To do this fist roll some cardstock or poster board around the PVC that you are using to make the motors to fly this model. I am using 1 inch PVC so I rolled the cardstock around the PVC and taped it after I was done to form a tube that the 1 inch PVC fits snugly into.

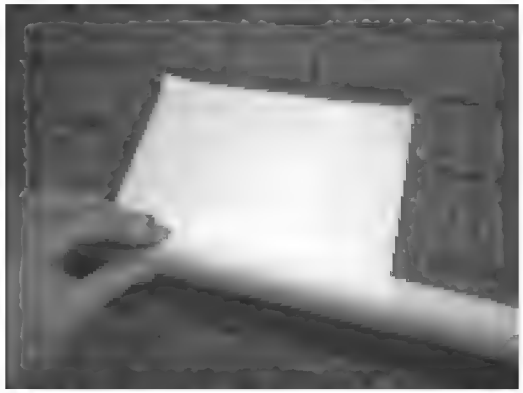


Figure 16-2: Rolling cardstock around PVC pipe to form a tube.

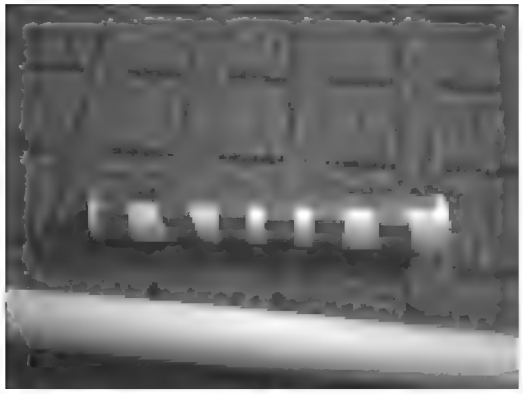


Figure 16-3: Cardstock tube removed from PVC and taped up to keep it from unrolling.

Now you need to mount this tube into the main body tube so you are going to need to make some cardboard rings to do this. Cut 2 cardboard circles out that fit inside the main body tube. I used the small section of the body tube to trace around on the cardboard sheet and then cut out the circles.

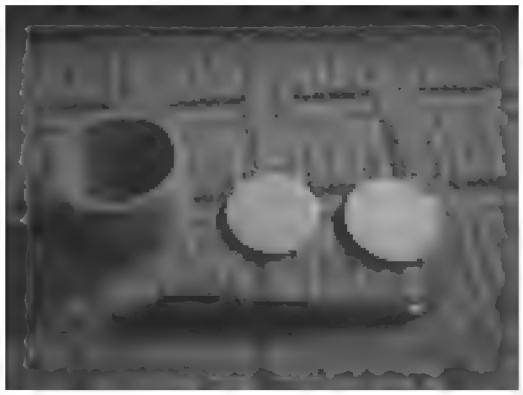


Figure 16-4: Cardboard circles cut out from tracing them using a small piece of body tube.

Now cut out the center of your cardboard circles so they fit around the cardstock tube you just made. Now place the cardboard ring around the cardstock motor mount and glue it in place with hot glue.

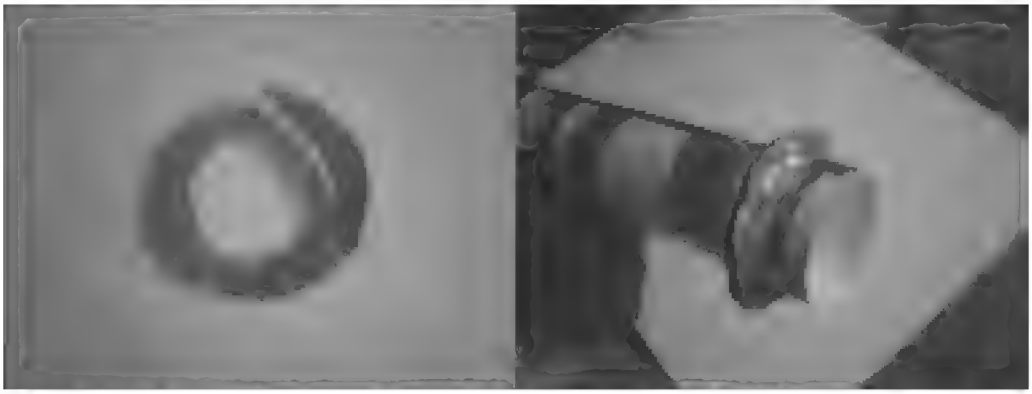


Figure 16-5: The center is cut out of the cardboard circle and glued with hot glue on motor mount.

Now do the same with the other cardboard circle and glue it on the other end of the motor mount tube.

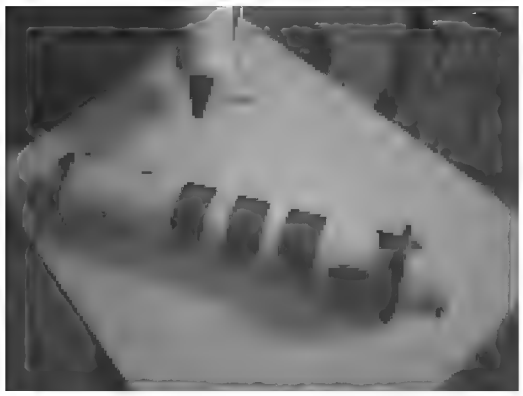


Figure 16-6: Finished motor mount with 2 cardboard rings glued in place.

Now your motor mount is completed and ready to be installed into the main body tube. Just apply some hot glue to the cardboard rings and slide the mount into the rear of the body tube until it is flush with the end of the tube. Now fill the space between the motor mount and the body tube with hot glue for extra strength.

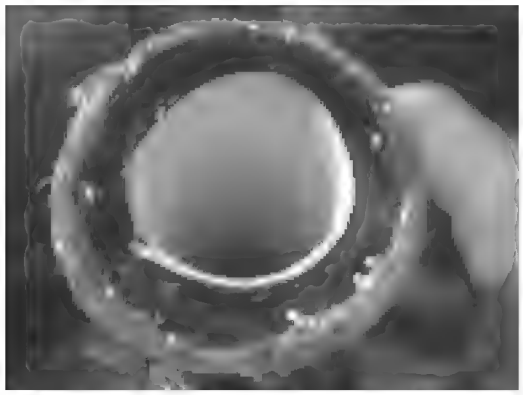


Figure 16-7: Motor mount installed and glued in place in main body tube.

Now you can cut out some tail fins. You can use balsa wood or I just use cardboard sheets. Be creative and make any aerodynamic design you want.

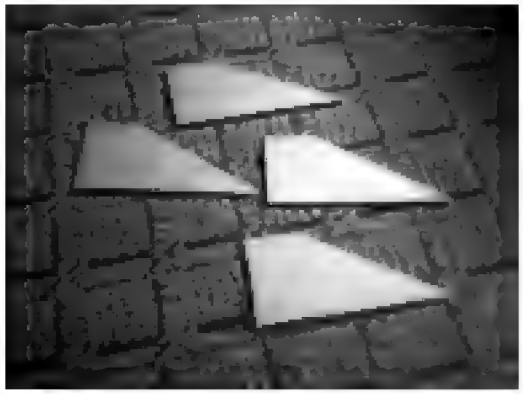


Figure 16-8: Tail fins cut out of cardboard.

Just glue the tail fins in place on the main body tube with hot glue in whatever arrangement you like for your design.

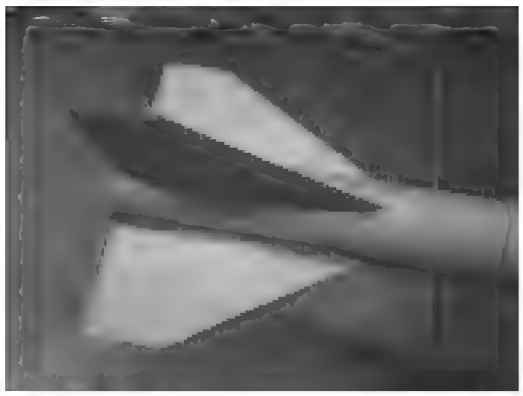


Figure 16-9: Tail fins glued on to main rocket body.

Now you need to make a nose cone assembly. Get that small piece of cardboard body tube you cut off and wrap some cardstock inside the tube and tape it so the cardstock can't unravel. You are trying to make a cardboard tube that fits inside the main body tube snugly.

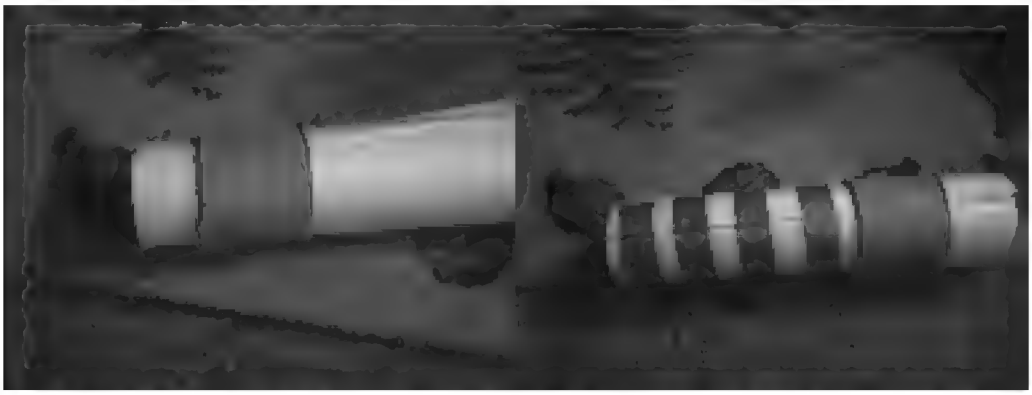


Figure 16-10: Rolling and taping cardstock to make a tube insert for the nose assembly.

Now cut this piece of cardboard to length so that it is inside the small chunk of body tube a few inches and it should stick out a couple inches. This is so it can slide into the main body tube easily and it will stay on but will slide off if necessary. This is so the nose cone assembly will come off when the parachute ejection pushes the parachute out of the main body tube.

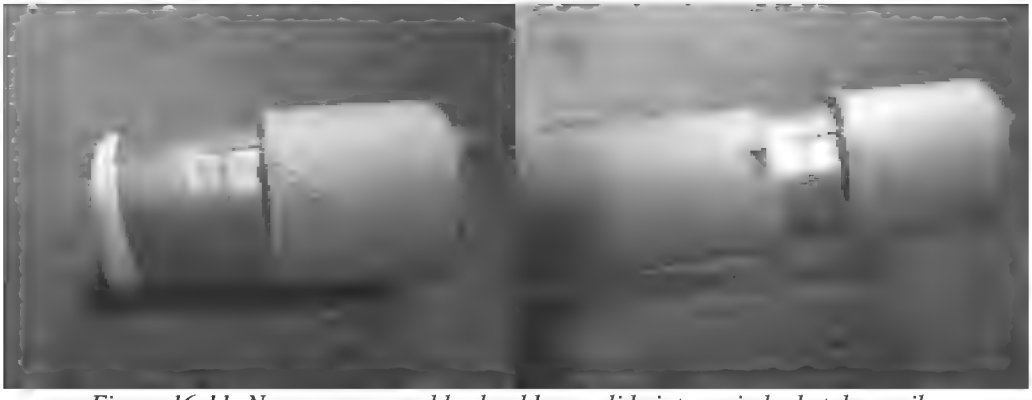


Figure 16-11: Nose cone assemble should now slide into main body tube easily.

Now you need to make an actual cone that goes on to your nose cone assembly to make your rocket more aerodynamic. You can carve a balsa nose cone if you wish but I just made one out of cardstock. Take the corners of the cardstock and fold them down and across each other so it forms a cone like in figure 16-12.

Just tape the paper in place to keep it from unraveling and trim it down to fit on top of the cardboard body tube of the rocket.

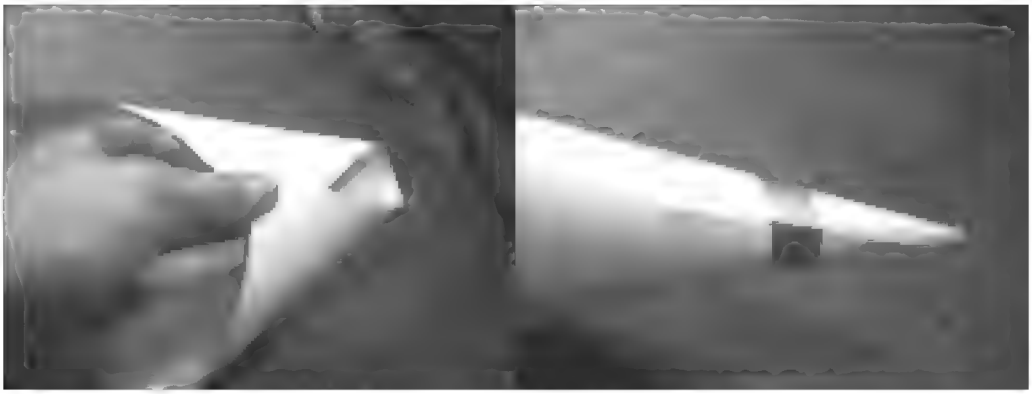


Figure 16-12: Fold the cardstock to form a cone and tape it.

Figure 16-13: trim the cone to fit on the main body tube of the rocket.

Now fill the tip of the nose cone with hot glue to make it hard and more durable.

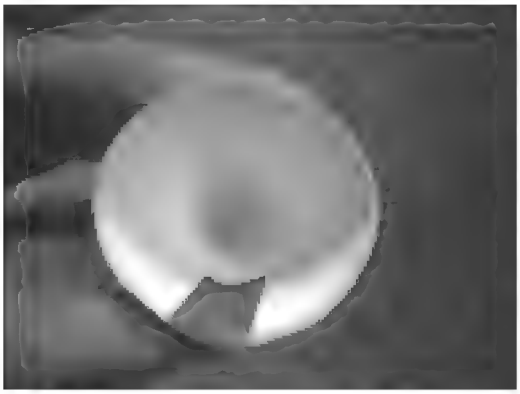


Figure 16-14: Fill the nose cone with hot glue to make it hard.

Now just glue the nose cone onto the nose cone assembly on the opposite end of the cardstock tube you made for it.

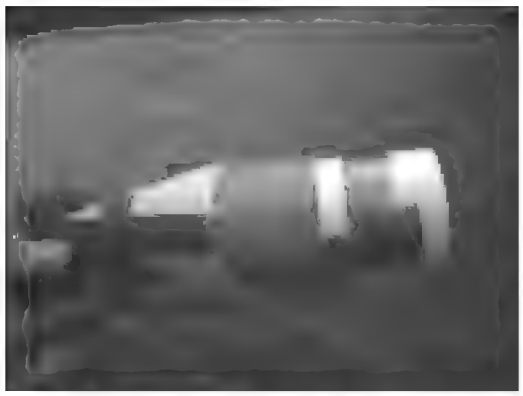


Figure 16-15: Nose cone glued on nose cone assembly.

Now you are going to need to attach everything together. Since the nose assembly will be popping off for the parachute to come out it will need a shock cord. For this I used some elastic that I bought in the sewing and crafts section of the store.

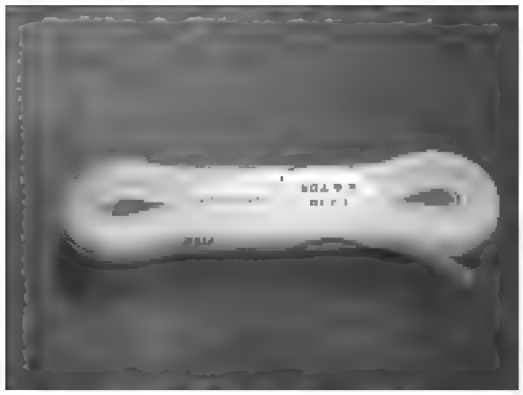


Figure 16-16: elastic banding.

Make a slit down far enough in the main body tube on the top that the nose cone assembly isn't going to hit it when inserted on the tube and pull some of the elastic banding through it. Tie a knot in the banding on the outside of the tube and hot glue it in place.

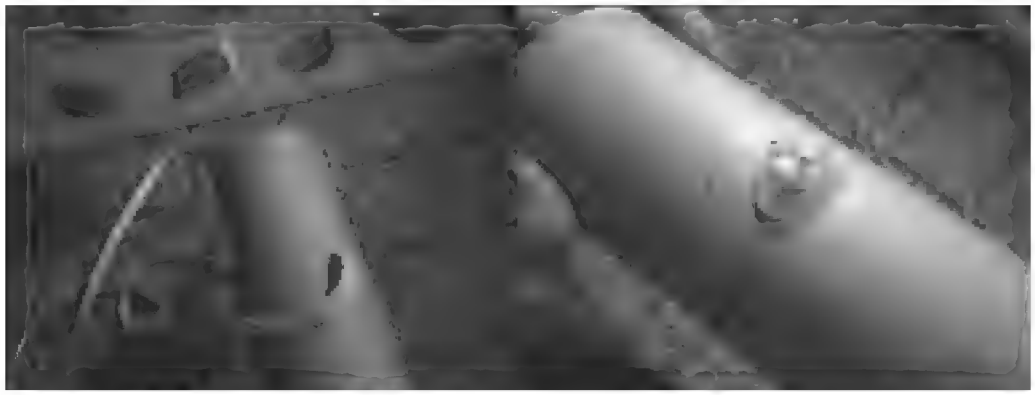


Figure 16-17: Elastic band pulled through a slit in the tube and knotted and glued in place.

Now make another slit in the nose cone assembly and do the same here and attach the length of elastic banding that is attached to the main body tube in the same manner but also pull another separate piece of elastic banding for the parachute through the same slit in the nose cone assembly and attach it. So now you

should have elastic banding from the main body tube to the nose cone assembly and another piece of banding from the nose cone assembly for attaching the parachute to.

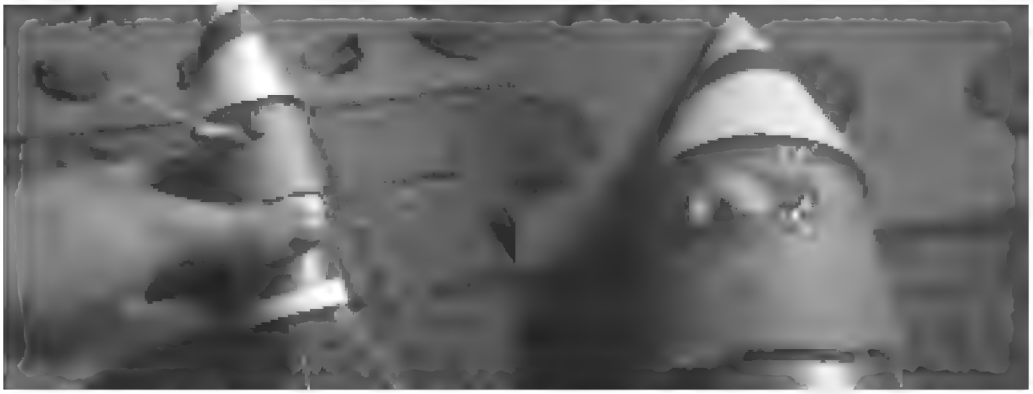


Figure 16-18: Elastic banding attached to the nose cone assembly and glued in place.

Now you need to make a parachute for your model rocket. For this I used nylon as my material. You can also use things such as plastic garbage bags. Cut your material into a square big enough that it will catch enough wind to slow your rockets decent. Now attached a piece of elastic banding to one corner of the square parachute and tie it in place.

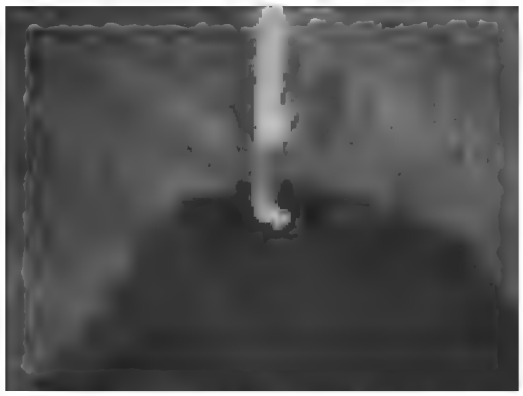


Figure 16-19: Tie elastic banding to the corners of the square parachute.

Now stretch the banding across the square to the opposite side and tie the other end of the banding to that corner of the square and do the same for the other 2 corners so you have an "X" of elastic banding tied to the square parachute.

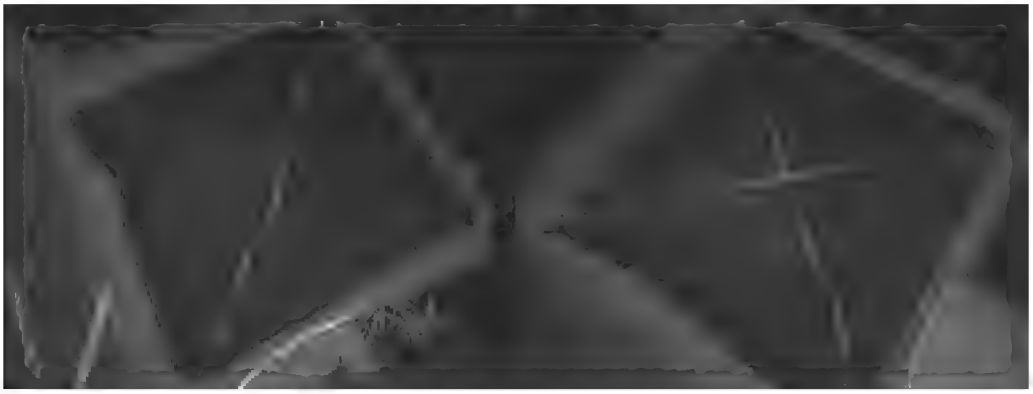


Figure 16-20: Elastic banding tied to all corners of the square parachute.

Now hold your parachute by the elastic banding so that all sides are hanging even to find the center of the elastic banding. Tie this center spot to the piece of elastic banding that is hanging from the nose cone assembly so now you have a piece of elastic going from the main body tube to the nose cone assembly and another piece of elastic going from the nose cone assembly to the center of the parachute strings.

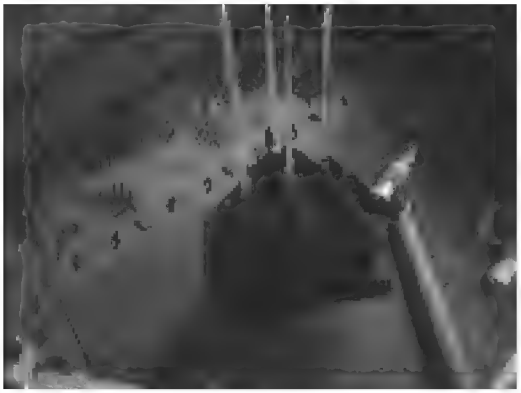


Figure 16-21: Find the center of the parachute strings by hanging it.

Now just roll the parachute up so it can be inserted into the body tube.

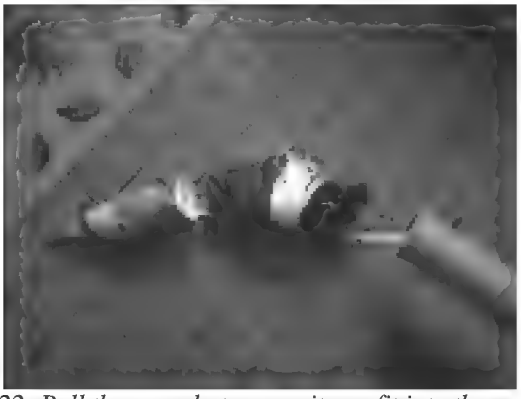


Figure 16-22: Roll the parachute up so it can fit into the model rocket.

Before you insert the parachute into the rocket you must have some wadding in between the rocket engine ejection charge and the parachute so the parachute doesn't burn up when it goes to fire it out of the tube. You can buy the non-flammable wadding for Estes rockets at most stores that you can use for this but any other nonflammable material will work. I just use a regular rag but to keep it from catching fire I dampen it with water just moments before flight. Just insert the damp rag into the rocket body tube trough the top and then insert the folded parachute and place the nose cone assembly on to the rocket.

There is one last thing you must have to be able to launch your rocket. You must have a launch lug to support the rocket for it's first few moments of flight and to guide it off the launch stand. For this I just glue a small piece of drinking straw to the side of the body tube. You can now slide the straw on the rocket down the 1/8-inch metal rod on the launch stand built in this book to guide your rocket.

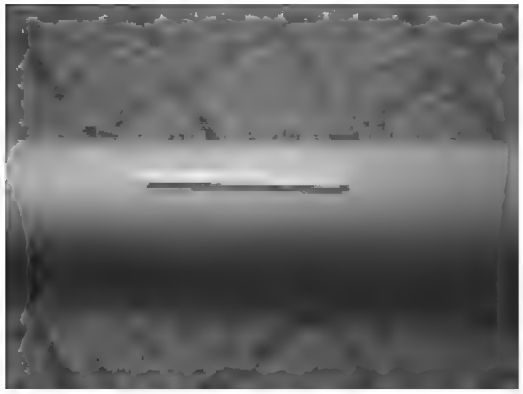


Figure 16-23: A drinking straw is used as a launch lug on the side of the rocket.

You now have a completed working model rocket with parachute recovery that is capable of flying on your homemade PVC engines! You may want to add a paint job as well to your rocket model to make it look better than it is in its current state.

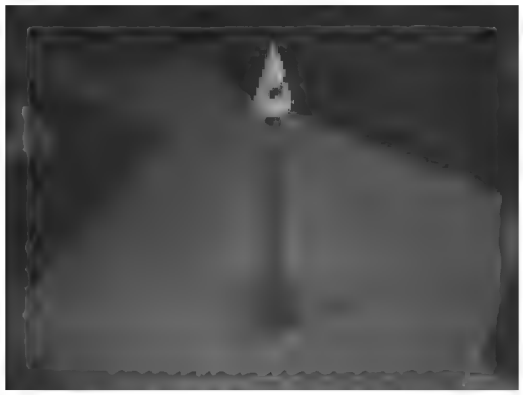


Figure 16-24: Completed model rocket ready to fly or have a paint job.

LAUNCH STAND

To fly your model rockets you are going to need a launch stand to help guide the rocket for its first few moments of flight. The launch stand presented here is simplistic but very functional. To start you are going to need a couple 2x4's that is a board that is 2 inches wide by 4 inches thick and depending on the size of your launch stand the length can vary. I cut my 2x4 board in half and each piece is about 3 feet long. Now you are going to have to notch each board in the center. Cut down in the board about 2 inches and make the cut 2 inches wide since the other board is 2 inches wide that way the other half will slide down onto it. Do this to each of the boards so you have a notch in each board in the center that is 2 inches by 2 inches. See the picture below for reference.

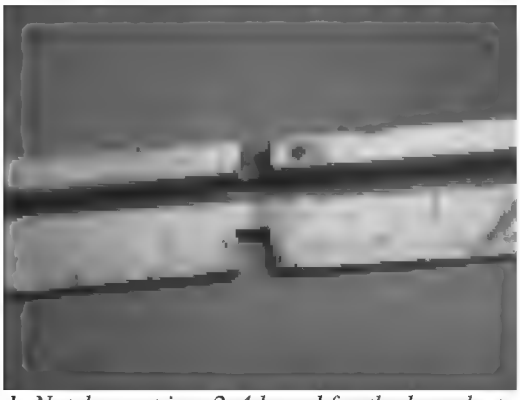


Figure 17-1: Notches cut in a 2x4 board for the launch stand bottom.

The boards should now fit into each other through the notches to form an "X" shape. Now drill a 1/8-inch hole in the center of the top board down to the notched part so you can fit in the launch rod. The launch rod consists of a 1/8-inch steel rod. You can purchase one of these from a hardware store. The rod should fit into the 1/8-inch hole in the center of your "X" of 2x4's.

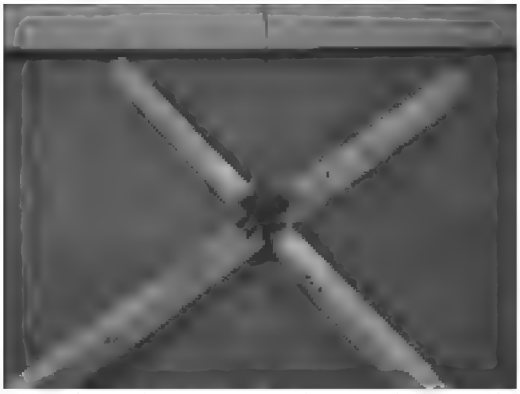


Figure 17-2: The stand now forms an "X" shape with the steel rod in the center.

Now you need a blast deflector to keep the hot exhaust gases from the rockets from scorching your launch stand and the ground around the launch pad. For my blast deflector I used an old pan. Make sure you use something made out of heavy metal so it doesn't melt or get damaged by the hot rocket exhausts. Just take a nail and punch a hole in the center of the pan about 1/8 inch in diameter so the launch rod can fit into the hole. And just slide the pan over the launch rod down to the 2x4's and that is it! Now just slide your launch lug on your rocket down the 1/8-inch steel rod and hook it up to fire.

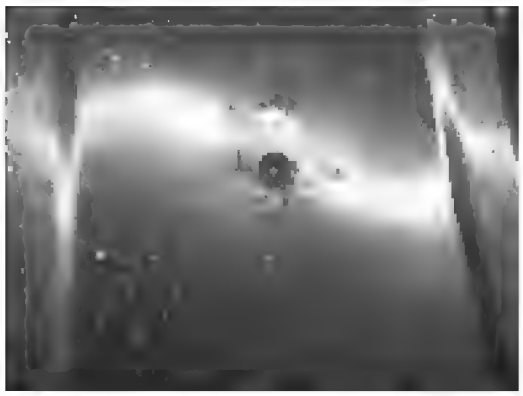


Figure 17-3: A 1/8 inch hole is punched in a pan with a nail so the steel rod can fit through it.

Figure 17-4: A finished launch stand with a rocket loaded on and ready to go.

PVC ENGINES AND COMMERCIAL ROCKET KITS

A commercial rocket engine, such as Estes, has a propellant based on black powder or "gun powder" and is an end burner, which means the propellant is simply packed straight into the tube and burns from the end to the top and has no core. This is because black powder burns fast enough on it's own to generate the required pressure to fly. These engines because of their design can be shorter in length, which makes it hard to make a core-burning engine the same size in length. It may prove to be difficult to fit these homemade PVC engines into a commercial rocket kit without modifying the rocket kit itself. And you can by all means modify rocket kits to fit your homemade engines by making a new motor mount and removing the old one.

You can make a new motor mount by wrapping some poster board or card stock around the PVC pipe that you used for your engines to make a tube and cut out rings of cardboard to mount it inside the rocket, which the process is described in the chapter "MAKING YOUR OWN MODEL ROCKET".

If you do not wish to modify your existing rocket then you can try and fit the engines you build to fit the rocket kit. The only thing you can modify here is the length of the motor. Commercial Estes rockets such as the A, B, and C size engines are almost the same outside diameter as the ½ inch CPVC pipe. They are 2-3/4 inches long so that limits the sizes of motors we can make fit the kit since anything over this isn't going to fit correctly. But the A7, B8, B11, and C15 motor designs in this book are under this length. So you can just make the A7, B8, B11, or C15 motor casings 2-3/4 inches long and keep everything thing else about the motor such as the nozzle and propellant the same and you should have plenty of room to fit a parachute ejection and possibly still have some extra space left in the PVC pipe but that is ok. If you construct them like this then they should fit into your rocket kit. They may still be a little loose fitting around the edges but you can just build up the outside diameter of the motor by wrapping some masking tape around it until it makes for a snug fit into the rocket.

I have included the designs for the A7, B8, B11, and C15 motors to fit a commercial Estes rocket. These particular designs are presented with a 4 second time delay before parachute ejection so the designated motor names are A7-4, B8-4, B11-4, and C15-4.

Below is an explanation of the diagrams.

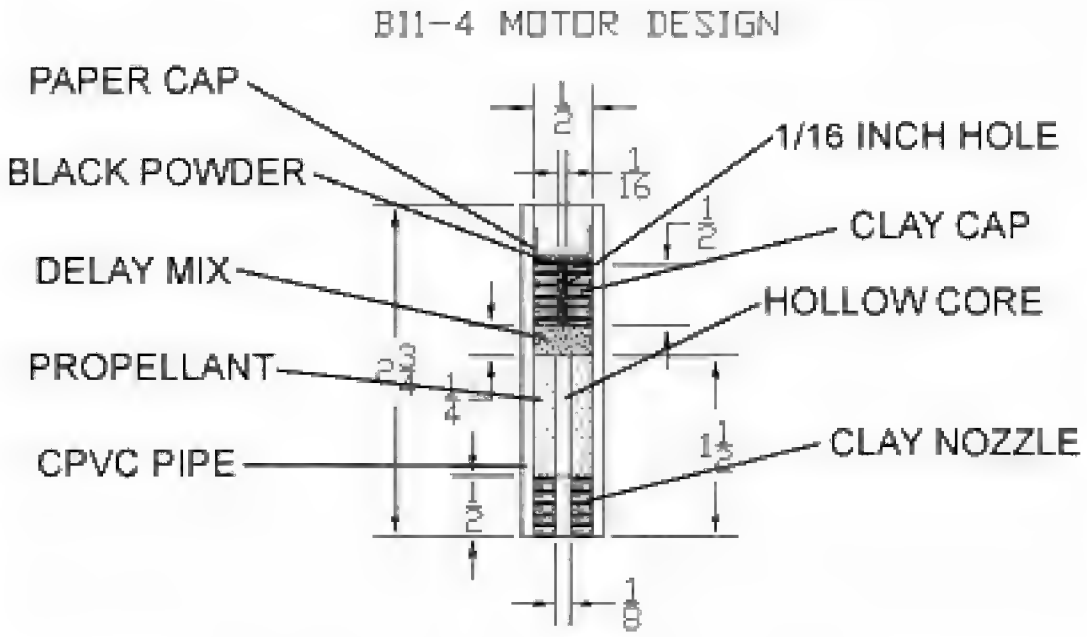
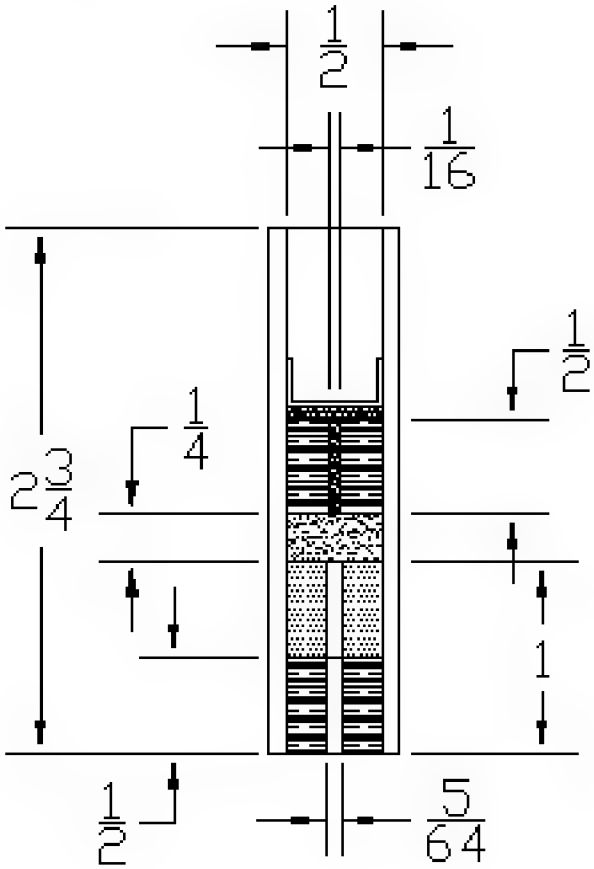
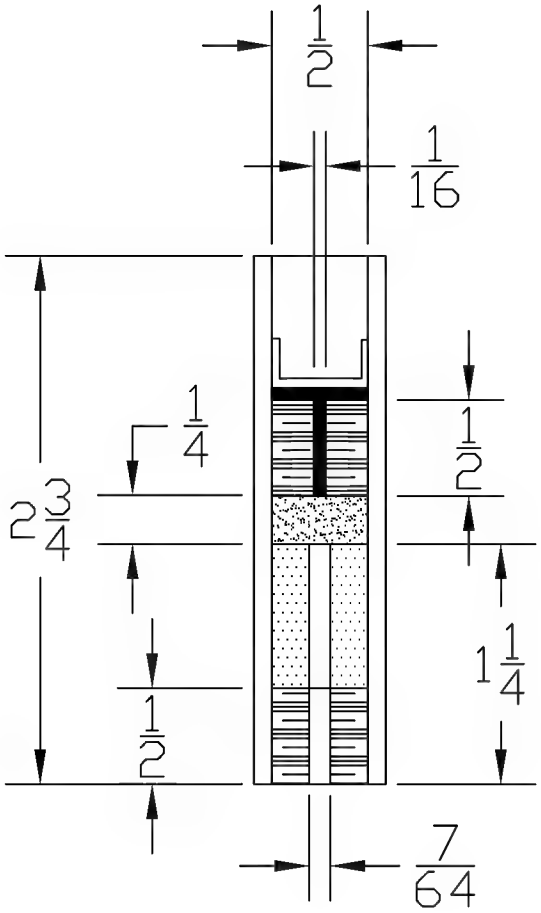


Figure 18-1: Explanation of diagrams with parts labeled.

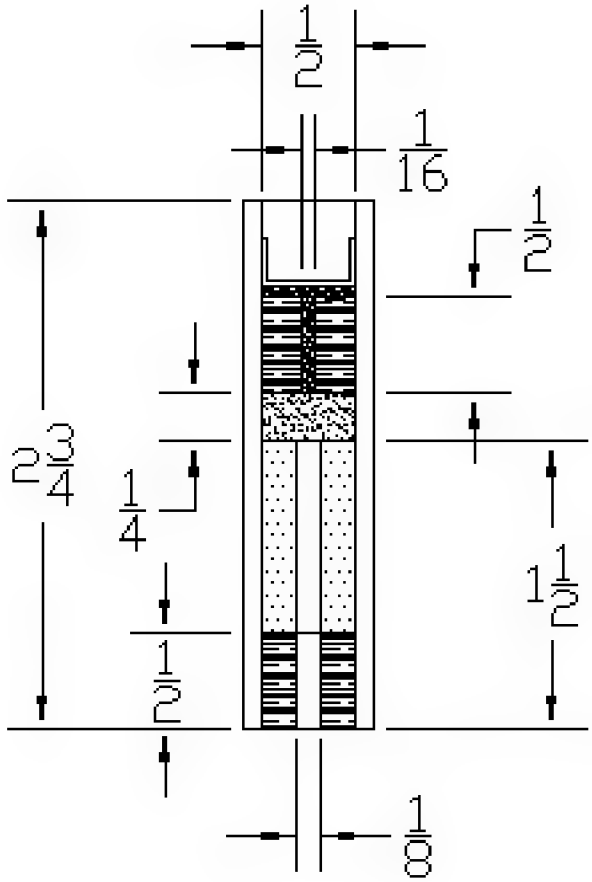
A7-4 MOTOR DESIGN



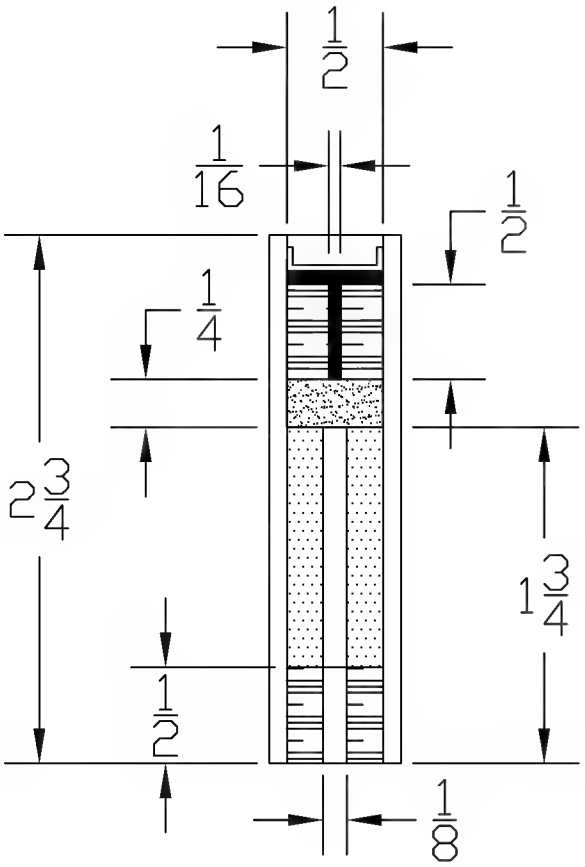
B8-4 MOTOR DESIGN



B11-4 MOTOR DESIGN



C15-4 MOTOR DESIGN



STORAGE

Storing the propellant and engines can be somewhat of a nuisance since the propellant is hydroscopic and draws moisture from the air and over time can render the engine or propellant useless. You cannot just let the propellant or engines lay out for prolonged periods of time. To keep the engines and propellant dry you must build a desiccator. A desiccator is a container with a desiccant that draws moisture out of the atmosphere to keep a product dry.

For my desiccator I use an airtight plastic container big enough to fit my rocket engines in. And for the desiccant I use calcium chloride or "rock salt" which you can buy at any grocery store for making ice cream. You can also find it as "road salt" for melting ice and snow. Regular table salt (sodium chloride) should work as well if you chose to use that.

Figure 19-1: Rock salt is used as a desiccant.

Just dump the salt into the airtight container and place your rocket engines into a "zip lock" bag and put it in the salt and seal it up. This should keep the engines dry until you are ready to fire them.

Figure 19-2: An airtight container is used with salt in it for a desiccator.

For storing propellant just place the propellant into a plastic bag and tie it shut or I use a "zip-lock" bag and then just place the bag into the homemade desiccator.

TROUBLESHOOTING ENGINES

Sometimes you will make mistakes and your rocket engines will not work properly but that is part of the learning process involved in this hobby and I have made plenty of mistakes and have seen plenty of failed rocket engines. You just have to think about it and figure out what might be wrong and try to correct it for next time. I am writing this section to try and give you some possible situations on how the rocket may be failing and how to correct some situations but this is not by far every solution.

Q: My rocket doesn't fly it just sits there and burns, what is wrong?
A: Well if you followed the designs from this book then maybe the propellant is damp from not being stored properly. If you live in a humid climate then that could be a huge factor and it may prove to be hard to store your engines. Make sure you store them as described in the storage chapter. You can test to see if it is moisture by making a rocket engine on the spot and firing it right away and if it flies and you made it the same way as the other engine then it probably is a moisture problem. Another solution is to try and modify the formula some by adding a higher percentage of potassium nitrate. Or if you are experimenting with engines try lengthening the core there by giving it more power from the increase in surface area. Also make sure your clay isn't too damp because the propellant can get wet from this as well. Another thing is to make sure the model rocket isn't heavier than what the engine can handle.

Also check and make sure you grind your potassium nitrate to a fine powder because a course powder will burn more slowly causing the engine not to fly. And make sure your chemicals are thoroughly mixed.

Q: My rocket just blows out the nozzle or clay end cap, what is wrong?
A: There is too much pressure for your clay nozzle or end caps to handle in the engine. Try ramming your clay harder or make sure you added enough water to the nozzle clay to keep it sticking together better. Also make sure you grind your nozzle clay to a very fine powder since the finer the powder the better the clay will hold. If this is still happening try making the nozzle or clay end cap thicker by adding more clay that what the design calls for. Or you could modify the propellant by lowering the percentage of potassium nitrate. If you are experimenting with motor designs then make the hollow core shorter in the engine so there is less pressure.

Q: My rockets go crazy when I fly them and fly off to the side. What is wrong?
A: Make sure your rockets are properly balanced because if they are not balanced then they will not fly straight. Also make sure you drill the nozzles center because an off center nozzle can make a rocket fly crooked or spin in the air.

Q: My parachute didn't deploy what is wrong?
A: Either you did not use enough black powder to push the parachute out or the black powder failed to fire because the hole in the clay wasn't drilled the whole way through to the time delay.

Q: My parachute deployed too soon what is wrong?
A: You possibly drilled too far into the delay mix through the clay cap or you did not use enough delay mix to provide sufficient time.